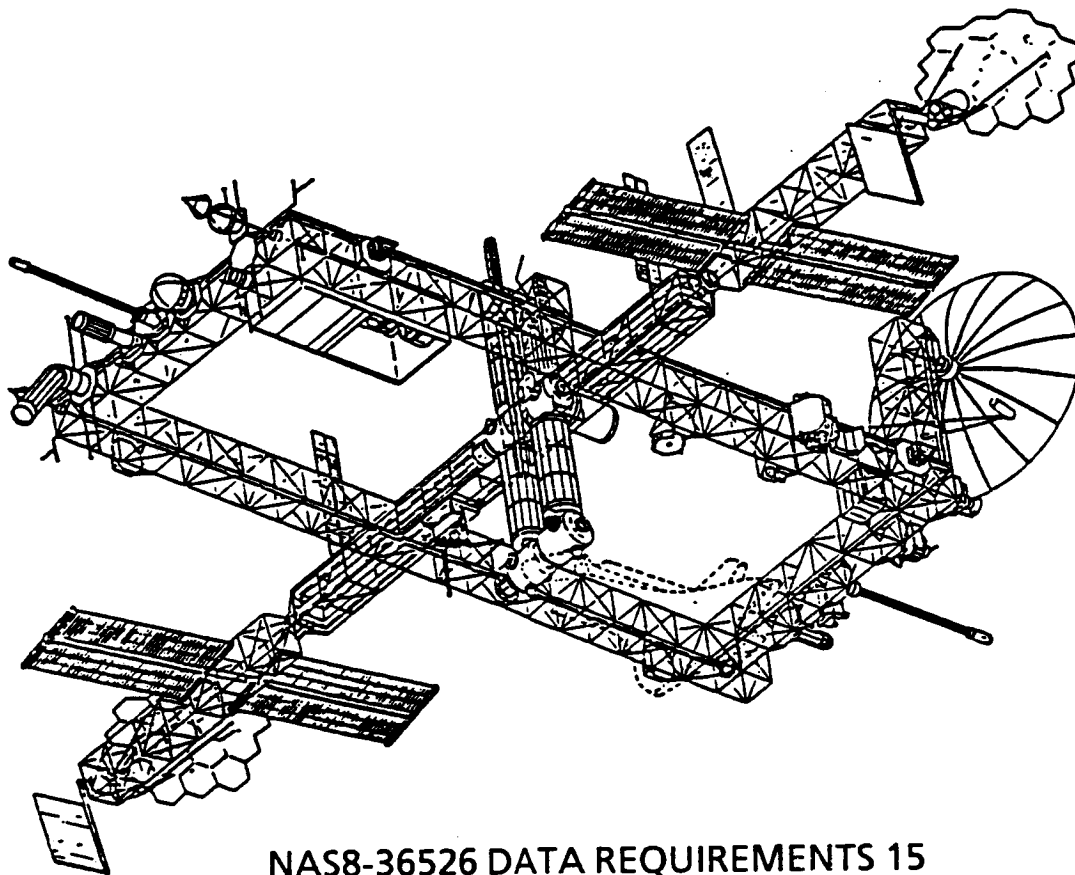


BOEING

Space Station

WP01



NAS8-36526 DATA REQUIREMENTS 15

FINAL STUDY REPORT

VOL II STUDY RESULTS

JANUARY 18, 1987

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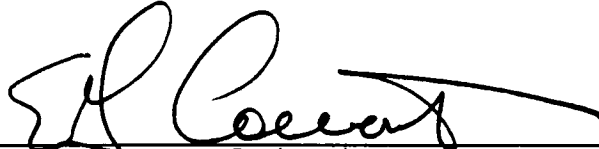
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**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER**

by

**BOEING AEROSPACE COMPANY
SPACE STATION PROGRAM
P.O. BOX 1470
HUNTSVILLE, ALABAMA 35807**

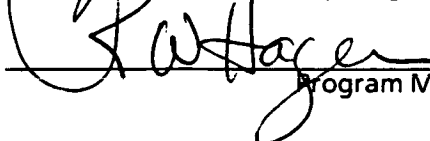
Approved by: E. G. Cowart


Engineering Mgr.

Approved by: J. B. Winch


Deputy Program Mgr.

Approved by: R. W. Hager
Vice President


Program Mgr.

ABSTRACT

Volume II, contained herein, of the Final Study Report provides a summary of significant study results that are products of the Phase B conceptual design task. This document is hereby submitted in accordance with the Phase B contract, NAS8-36526. Major elements of the study effort are addressed in this volume. Study results applicable to each major element or area of design are summarized and included where appropriate.

KEY WORDS

Accommodations	Materials
Ada	Modules
Analyses	Permanently Manned
Artificial Intelligence	Preliminary
Automation	Pressurized
Autonomy	Process
Baseline	Product Assurance
Concept	Productivity
Configuration	Rack
Cost	Requirements
Customer	Robotics
Data Requirement	Safehaven
Design	Safety
Design to Cost	Servicing
Development	Software
Electromagnetic Interference	Software Support
Elements	Environment
End Item	Specification
Environment	Statement of Work
Final Operational Capability	Subsystems
Growth	System
Hardware	Technology
Human Factor	Telerobotics
Implementation	Vacuum
Initial Operational Capability	Work Package
Integration	
Interface	

TABLE OF CONTENTS

1.0	INTRODUCTION	11
1.1	Scope	11
2.0	SYSTEM ENGINEERING AND INTEGRATION (SE&I)	12
2.1	Systems	12
2.1.1	Systems Engineering and Integration (SE&I)	12
2.1.2	SE&I Plan	12
2.1.3	Requirements Development	12
2.1.4	Interface Requirements Documents (IRDs)	12
2.1.5	System Requirements Document (SRD)	12
2.1.6	Contract End Item Specifications (CEI's)	13
2.1.7	Preliminary Design Data	14
2.2	Man Tended	14
2.2.1	Man Tended Strategy and Approach	14
2.2.2	Man Tended Study Flow	14
2.2.3	Man Tended Results	16
2.3	Automation and Robotics	16
2.3.1	Introduction	16
2.3.2	Scope	16
2.3.3	Approach	16
2.3.4	Selection Criteria	17
2.4	Space Station Evolutionary Process	23
2.4.1	Contract Start Date (C&D) Configuration	23
2.4.2	RUR-1 Configuration	23
2.4.3	RUR-2 Configuration	23
2.4.4	IRR Configuration	23
2.4.5	SRR Configuration	23
2.4.6	Post SRR Configuration	24
2.5	Software Development	24
2.5.1	External and Internal I/F Definition	24
2.5.2	Software Support Environment	24
2.5.3	Requirements for the SSE	39
3.0	CUSTOMER ACCOMMODATIONS	60
3.1	Purpose	60
3.2	Approach	60
3.3	The United States Laboratory Module	60
3.4	Procedures for Customer Access	60
3.5	Space Station Initial Operating Capability	60
3.6	Module Growth	60
3.7	U.S. Laboratory Module	65
3.7.1	Scope of Research and Development Accommodated	65
3.7.2	Internal Environment	68
3.7.3	External Environment	81
3.7.4	Resources	82
3.7.5	Safety	84
3.7.6	Customer Relationships	87

TABLE OF CONTENTS (Continued)

4.0	WP-01 TEST AND VERIFICATION PROGRAM	89
4.1	Overview	89
4.1.1	Verification Program Interfaces	89
4.1.2	Planning Precepts	89
4.1.3	Protoflight Philosophy	91
4.1.4	Maintainability Demonstration	91
4.1.5	Maintainability Verification	91
4.2	Verification Requirements Derivation	93
4.3	Design Verification	94
4.3.1	System Integration Testing	100
4.3.2	Element Protoflight Tests	102
4.3.3	Qualification Tests	107
4.4	Hardware Verification	109
4.4.1	General Acceptance Test Requirements	109
4.4.2	Element Acceptance Tests	109
4.4.3	FSE Acceptance Tests	110
4.4.4	Subsystem Acceptance Tests	110
4.4.5	Component/ORU Acceptance Tests	110
4.4.6	Ground Support Equipment Acceptance Tests	110
4.5	Space Station Ground Systems Verification	110
4.5.1	Ground Support Equipment Verification	110
4.5.2	Launch Readiness Verification	111
4.6	Test Planning and Conduct	111
5.0	PRODUCT ASSURANCE	113
5.1	Summary of Safety Analysis Findings	113
5.2	Failure Mode and Effect Analysis (FMEA)	115
5.2.1	Criticality 1 Items	148
5.2.2	Criticality 2 Items	148
6.0	CONCEPTUAL DESIGN	199
6.1	Configuration	199
6.2	Common Module (Core) Subsystems	199
6.2.1	Structures and Mechanisms	203
6.2.2	Baseline Structural Description	204
6.2.3	Electrical Power Subsystem	218
6.2.4	Data Management Network Distribution System (DMNDS)	225
6.2.5	Audio/Video Distribution Systems (AVDS)	229
6.2.6	Common Module Thermal Control System (TCS)	232
6.2.7	Crew Systems	233
6.3	Environmental Control Life Support System (ECLSS)	233
6.3.1	Requirements	233
6.3.2	ECLSS Baseline Design	241
6.3.3	Waste Management Systems (WMS)	264
6.3.4	Fire Detection and Suppression	266
6.4	Laboratory Module Outfitting	267
6.4.1	Configuration	267

TABLE OF CONTENTS (Continued)

6.4.2	USL Module	267
6.4.3	Process Materials Management	276
6.4.4	Emergency Shower	287
6.4.5	Laboratory Support Equipment	298
6.5	Introduction	302
6.5.1	Requirements	302
6.5.2	System Configuration	320
6.6	Vehicle Accommodations	321
6.6.1	OMV Accommodations	321
6.6.2	OTV Accommodations	334
6.6.3	Smart Front End	339
6.7	Propulsion System	358
6.7.1	Propulsion Subsystem Requirements	358
6.7.2	Propulsion Subsystem Baseline Configuration Description	360
6.7.3	Reboost	369
6.8	Airlocks	373
6.8.1	Airlock	373
6.8.2	Hyperbaric Airlock	374
6.9	Resource Nodes	374
6.10	Habitation Module	374
6.10.1	Crew Quarters	375
6.10.2	HMF Exercise Area	375
6.10.3	HMF Medical Facility	375
6.10.4	Wardroom	375
6.10.5	Waste Management	377
6.10.6	Galley	377
6.10.7	Shower	377
6.10.8	Laundry	377
6.10.9	Multi-Purpose Applications Console (MPAC)	377
6.10.10	Reserved	377
6.10.11	Storage	377
6.10.12	Safe Haven	377
6.10.13	Electrical Power Distribution System	378
6.10.14	HAB Module Thermal Control Subsystem	378
6.10.15	Data Management System (DMS)	378
6.10.16	Structural and Mechanical Components	384
6.10.17	ECLSS	390
7.0	OPERATIONS AND PLANNING	393
7.1	Prelaunch and Postlanding	393
7.1.1	Ground Operations	393
7.1.2	Top Level NASA Requirements	393
7.1.3	Verification Requirements	396
7.1.4	IOC Processing Concepts	399
7.1.5	Operational Phase Processing Concepts	401
7.1.6	Ground Support Requirements	403
7.1.7	Customer Interfaces	406

TABLE OF CONTENTS (Continued)

7.1.8	Safety and Security	407
7.2	Orbital Operations Approach Planning	408
7.2.1	Assembly Phase	408
7.2.2	IOC Phase Ground Support Operations	414
7.2.3	On-Orbit Operations	423
7.3	Logistics and Resupply Approach Planning	437
7.3.1	Organizational Relationships and Responsibilities	437
7.3.2	Logistics Management Information	437
7.3.3	Logistics Support Analysis (LSA)	438
7.3.4	Logistics Elements	438
7.4	On-Orbit Maintenance Approach Planning	442
7.4.1.	Maintenance Types	442
7.4.2	Procedures and Data Development	443
7.4.3	Mission Set Maintenance Procedures	443
8.0	ADVANCED DEVELOPMENT	444
8.1	Advanced Development Activities	444
8.1.1	AR-1 Automation and Robotics	444
8.1.2	EC-1 ECLSS Water Management	445
8.1.3	EC-2 ECLSS Air Management	446
8.1.4	EC-3 Air and Water Monitors	447
8.1.5	EC-4 Component/Subsystem Test and Evaluation	447
8.1.6	PO1/2 Electric Power Distribution Network and Control Architecture	448
8.1.7	TH-1 Thermal Interface Development	449
8.1.8	MS-1 MPAC Element Demonstrator	450
8.1.9	AP-1 Propulsion and Fluids Systems	453
8.1.10	Meteoroid/Debris Impact Shield Testing	464
8.1.11	DM-1 System Controller Development for Data Management Systems	465
8.1.12	DM-2 Hierarchical Controller Development	470
8.2	Advanced Development Growth Recommendations	470
8.2.1	Data Management and Communications	470
8.2.2	Electrical/Electronic	471
8.2.4	Propulsion/Fluid Management	472
8.2.5	ECLSS	472
8.2.6	Software	473
8.2.7	Automation/Robotics	473
9.0	TECHNICAL AND MANAGEMENT INFORMATION SYSTEM (TMIS)	475
9.1	Description	475
9.2	TMIS Engineering Systems	475
9.2.1	Analytical Systems and Supporting Tools	477
9.2.2	Computer Aided Design System	477
9.2.3	Engineering Computer Data Storage	478

LIST OF FIGURES

Figure		Sheet
2.1-1	Specification Tree	15
2.3-1	Candidate Application WP-01 Elements	20
2.3-2	On-Orbit Activity Time Percentages	21
2.3-3	Methodology for Evaluating Crew Utilization of A&R Candidate	22
2.5-1	Data Flow Diagram	25
2.5-2	Data Flow Diagram	26
3.4-1	Customer Accommodations Flow Chart	61
3.5-1	Space Station Initial Operating Configuration	62
3.5-2	Space Station Initial Operating Configuration(Module Assembly)	63
3.5-3	Microgravity Environment Around The Space Station	64
3.7.1-1	Types of R&D Activity Performed at The Space Station	66
3.7.2.1-1	USL Module Dimensions	76
3.7.2.1-2	USL Module Cross-section	77
3.7.2.1-3	Standard Rack Dimensions	78
3.7.2.1-4	USL Hatch Dimensions	79
3.7.2.2-1	Respirable Atmosphere/Water Requirements	80
4.1-1	Wp-01 Elements Test and Verification Flow	90
4.2-1	Verification Requirements Allocation Method	95
4.2-2	VCRI and Verification Allocation Formats	96
4.2-3	TCS DDT&E Flow Sheet 1 of 2	97
4.2-3	TCS DDT&E Flow Sheet 2 of 2	98
4.2-4	Equipment Test Requirement Matrix	99
4.3-1	Qualification Testing Decision Process	101
4.3-2	SIL Support Concept	103
4.3-3	Systems Integration Laboratory Configuration Evolution	104
4.3-4	SIL Interface	105
4.6-1	Typical Boeing Test Flow	112
5.2-1	Functional Breakdown	141
5.2-2	Volume 1	142
5.2-3	Volume 2	143
5.2-4	Volume 3	144
5.2-5	Volume 4	145
5.2-6	Volume 5	146
5.2-7	Volume 6	147
6.1-1	Manned-Core Space Station with International Partners and Two U.S. Modules .	200
6.1-2	Space Station Payload Accommodation	201
6.1-3	Two U.S. Module Pattern	202
6.2.2.1-1	Common Module Structural Arrangements	208
6.2.2.1-2	Trunnion and Keel Pin Assemblies	209
6.2.2.1-3	Trunnion and Keel Pin Assemblies	210
6.2.2.1-4	Trunnion and Keel Pin Assemblies	211
6.2.2.1-5	Berthing Ring	212
6.2.2.1-6	Hatch Design	213
6.2.2.1-7	Rotary Feed Through Mechanisms	214
6.2.2.1-8	Hatch Design	215

LIST OF FIGURES (Continued)

6.2.2.1-9	Common Module Window	216
6.2.2.2-1	Meteoroid/Debris, Radiation and Thermal Protection	217
6.2.2.3-1	Common Module Payload Structure	219
6.2.2.3-2	Rack Envelope	220
6.2.3.1.10-1	USL EPS Functional Schematic	223
6.2.3.1.10-2	Common Module Power Distribution Layout	224
6.2.4.1-1	DMNDS Layout	226
6.3.1.1-1	Space Station ECLSS System/Subsystem Functional Integration Control	236
6.4.2.1-1	Common Module Envelope Dimensions	268
6.4.2.1-2	Symmetric 4 Standoff Configuration	269
6.4.2.1-3	Standard Rack Locations	270
6.4.2.1-4	Standard Rack and Functional Unit Envelope	272
6.4.2.1-5	Rack and Functional Unit Envelope	273
6.4.2.3.2-1	USL Configuration	277
6.4.3.2.1-1	Inert Process Gas Distribution System	280
6.4.3.2.1-2	Oxygen Process Gas Distribution System	281
6.4.3.2.1-3	Nitrogen Process Gas Distribution System	282
6.4.3.2.1-4	Helium Process Gas Distribution System	283
6.4.3.2.1-5	Liquid Nitrogen Process Fluid Distribution System	284
6.4.3.2.1-6	Process Water Distribution System	285
6.4.4.6.1-1	USL Emergency Shower Concept 1	292
6.4.4.6.1-2	USL Emergency Shower Concept 2	293
6.4.4.6.1-3	Emergency Shower Concept 1 & 2 Activation Scenario	294
6.4.4.6.1-4	USL Emergency Shower Concept 3	295
6.4.4.6.1-5	USL Emergency Shower Concept 3 Activation Scenario	296
6.4.5.1-1	Equipment Source Selection	301
6.5.1.8-1	90-day Requirements-Crew Support-Dry Cargo-Up-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	306
6.5.1.8-2	90-day Requirements-Crew Support-Dry Cargo-Dowin-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	307
6.5.1.8-3	90-day Requirements-Station Support-Dry Cargo-Up-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	308
6.5.1.8-4	90-day Requirements-Station Support-Dry Cargo-Down-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	309
6.5.1.8-5	90-day Requirements-Customer Support-Dry Cargo-Up-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	310
6.5.1.8-6	90-day Requirements-Customer Support-Dry Cargo-Down-IOC Prime (Pressurized Module and Unpressurized Dry Cargo Carrier)	311
6.5.1.8-7	90-day Requirements-Station Support-Fluids-Up-IOC Prime (ECLSS and Lab Fluids and Propellants Carriers)	312
6.5.1.8-8	90-day Requirements-Customer Support-Fluids-Up-IOC Prime (ECLSS and Lab Fluids and Propellants Carriers)	313
6.5.1.8-9	90-day Requirements-Customer Support-Fluids-Up-IOC Prime (ECLSS and Lab Fluids and Propellants Carriers)	314
6.5.2.1-1	Pressurized Module	322
6.5.2.1-2	Pressurized Module	323
6.5.2.1-3	Pressurized Module	324

LIST OF FIGURES (Continued)

6.5.2.2-1	Unpressurized Dry Cargo Carrier	325
6.5.2.3-1	Propellant Carrier	326
6.5.2.4-1	Fluids Carrier	327
6.6.1.1-1	Baseline OMV Space Station Configuration	329
6.6.1.3-1	Operational Scenario	330
6.6.1.3-2	OMV Accommodations OMV Servicing Flow Timeline	331
6.6.1.3-3	OMV Accommodations	332
6.6.2.1-1	OTV Space Station Reference Configuration	336
6.6.2.2-1	Space Station Operations Scenario	338
6.6.2.3-1	Mission Model Flight Frequency (Low Module)	340
6.6.2.3-2	Mission Model Flight Frequency (Nominal Model)	341
6.6.2.3-3	OTV Mission Model Composition Summary	342
6.6.3.4-1	SFE Drawing Tree	344
6.6.3.4-2	Smart Front End	347
6.6.3.4.2-1	Smart Front End, Exploded View	349
6.6.3.4.2-2	ORU Carrier, Structural Frame	350
6.6.3.4.2-3	Smart Front End, Shuttle Transport	351
6.6.3.4.2-4	ORU Carrier, Camera and Boom	352
6.6.3.4.2-5	ORU Carrier, Satellite Interfaces/Stablizer	353
6.6.3.4.2-6	ORU Carrier, Positioning Arm	354
6.6.3.6.2-1	SFE Servicing Spartan	357
6.7.2-1a	O ₂ /H ₂ Connected Modular Propulsion System Schematic	361
6.7.2-1b	O ₂ /H ₂ Connected Modular Propulsion System Schematic	362
6.7.2-1c	O ₂ /H ₂ Connected Modular Propulsion System Schematic	363
6.7.2-1d	O ₂ /H ₂ Connected Modular Propulsion System Schematic	364
6.7.2-1e	O ₂ /H ₂ Connected Modular Propulsion System Schematic	365
6.7.2-2	2-sigma and Norminal Atmosphere Annual Impulse Requirements	366
6.7.2-3	Space Station O ₂ /H ₂ Water Electrolysis Propulsion Subsystem Locations	367
6.10-1	HAB Module Rack Layout	376
6.10.13-1	EPS Functional Diagram	379
6.10.13-2	HAB Module ESP Layout	380
6.10.14-1	HAB Module TCS Functional Flow Schematic	381
6.10.16.1-1	HAB Module/Orbiter Cargo Bay Envelope	385
6.10.16.8-1	HAB Module Audio Subsystem	388
6.10.16.9-1	Video Architecture	389
6.10.17-1	ECLSS Schematic Diagram	391
7.1.1-1	Launch Site Test and Operations Flow	394
7.1.5.1-1	Logistics Element Resupply Flow	402
8.1.7.4-1	Interface Heat Exchanger Test Facility Schematic	451
8.1.9.1.1-1	Extended Life Thruster Duty Cycle	455
8.1.9.2.3-1	Test Cell and Thruster Schematic	457
8.1.9.2.3-2	Augmentation Ratio for Waste Gas Addition to Hydrazine Thruster	458
8.1.9.3.2-1	Minimum Spillage Fluid Connector	462
8.1.9.4-1	O ₂ /H ₂ Electrolysis - Propulsion Test Team	463
8.1.10-1	ADP SM-1 Meteoriod Debris Impact Shield Testing	466
8.1.10-2	ADP SM-1 Meteoriod Debris Impact Shield Testing	467
8.1.10-3	ADP SM-1 Meteoriod Debris Impact Shield Testing	468

LIST OF FIGURES (Continued)

9.1-1	Technical and Management Information System	476
9.2.3-1	Engineering Dataset Storage	479
9.2.3.1-1	Engineering Release and Control of Datasets	480
9.2.2.4-1	TMIS Data Transfer Interconnections	481

LIST OF TABLES

Table	Sheet
2.5-I	DFD Dictionary 27
3.7.1.2-I	Class of Payload According to Physical Characteristics: Vapor Phase
	Crystal Growth 67
3.7.1.3-I	Near-, Mid-, Far-Term Station Accommodation Test Sets (SATS) 69
3.7.1.3-II	Contents of Near-Term SATS Set #1 70
3.7.1.3-III	Examples of Experiment Themes, by Discipline 75
4.1-I	Key WP-01 Verification Requirements and Concepts 92
4.3-I	Preliminary SIL Facility Requirements 106
5.2-i	Fmea Description of Entries 149
6.2-I	A Common Module Structural Requirements 206
6.2.2-II	Common Module Weight Statement 207
6.2.7.1-I	Crew Station Design Philosophies 234
6.2.7.1-II	Information System Philosophies 235
6.3.1.2-I	Respirable Atmosphere/Water Requirements 239
6.3.1.2-II	Respirable Atmosphere Water Requirements (SI Units) 240
6.3.2.4-III	Environmental Control Life Support System Equipment List Configuration IOC
	Prime Crew Size 8 245
6.4.3.3-I	Process Fluid Distribution Subsystem Weights (kg) 288
6.4.4.6.2-I	Emergency Shower Components 297
6.4.4.6.7-I	Emergency Shower Mass Property - Concept 1&2 299
6.4.4.6.7-II	Emergency Shower Mass Property - Concept 3 300
6.5.1.11.2-I	Factors of Safety 317
6.6.1.3-I	OMV Accommodations Control Functions (Customary Units) 333
6.6.2.2-I	OTV Accommodations Mass Summary 337
6.6.3.4-I	SFE Interface Requirements 343
6.6.3.4-II	Smart Front End Elements 345
6.7.3.2.2-I	Reference Configuration Impulse Allocations 372
8.1.9.2.3-I	Impulse Summary 460
8.1.9.3.1-I	Design Parameters 461

1.0 INTRODUCTION

This volume addresses major Statement of Work (SOW) tasks as defined in the Phase B Contract, NAS8-36526. This document is submitted in response to Data Requirement (DR) 15, Final Study Report. The contents contained herein reflect not only the original tasks described, but also reflect deviations to original Work Package (WP) definition which has resulted from realignment of WP Elements throughout the course of Phase B.

1.1 Scope

The contents in this document provide Phase B final study results. Significant results are provided for each identified element. References are made DR that contain Phase B preliminary design detailed data where applicable.

2.0 SYSTEM ENGINEERING AND INTEGRATION (SE&I)

2.1 Systems

Dynamic conceptual design development, response to changes in requirements and performance of trades and analyses have been key elements of the Phase B study effort.

2.1.1 Systems Engineering and Integration (SE&I)

Defining the system and allocating requirements to configuration items are prime tasks essential to baselining a configuration. A brief synopsis of the SE&I effort for accomplishing this task is included herein.

Methodology incorporated was to support definition and integration of WP-01 end items and provide data to support Space Station definition, planning and the establishment of system and interface requirements and traceability. Performance of trade studies and analyses, cost and technical performance measurements, support of technical reviews and working groups and integration of contract tasks into the system definition and WP element and subsystem design also played major roles in the SE&I effort.

Trades and analyses were conducted, concept options investigated and design to cost and technical performance measurement completed. Systems integration allocated, controlled, and made change recommendations where necessary, on all requirements. Using the design team approach, inputs from task interfaces were integrated into the requirements. Trade Study products, including plans for software, automation and robotics and growth were provided per the SE&I plan schedule and are summarized in DR-02 (13.2f).

2.1.2 SE&I Plan

Boeing's SE&I effort followed and basically conformed to the Level B SE&I Plan included in the Phase B contract. DR-19, Time Phased SE&I Products, contains detailed products of the SE&I effort, including Engineering Master Schedules (EMS) development, rationale and themes.

2.1.3 Requirements Development

Support to the requirements development effort has involved the generation and/or review, evaluation and submittal of recommended changes to the various requirements documents produced during Phase B.

2.1.4 Interface Requirements Documents (IRDs)

IRDs were prepared in order to document and define the external interfaces existing between WPs. The effort was accomplished and delivered in accordance with DR-02.

2.1.5 System Requirements Document (SRD)

The SRD, which can be considered a system segment document was prepared in order to baseline WP-01 requirements. These requirements were established and documented in order to form the basis for the WP-01 end item requirements contained in the Part 1 Contract End Item Specifications. The document was generated by MSFC, with Boeing providing complete support in its review and evaluation.

2.1.6 Contract End Item Specifications (CEI's)

The production of the CEI specifications was accomplished and delivered in accordance with DR-03. A CEI specification was written for each designated WP end item. The documents were baselined and revised as necessary to accommodate WP realignment, changes in requirements and/or other miscellaneous revisions.

CEI's were produced for the following:

- a) SS-Spec-0002, U.S. Laboratory Specification
- b) SS-Spec-0003, Logistics Elements Specification
- c) SS-Spec-0004, Airlock Specification
- d) SS-Spec-0005, Hyperbaric Airlock Specification
- e) SS-Spec-0006, Resource Nodes Specification
- f) SS-Spec-0100, Habitation Module Specification

SS-SPEC-0002 U.S. LABORATORY SPECIFICATION

The U.S. Laboratory Module's major function will be to serve as a facility for materials and microgravity research and processing experiments. The laboratory will be an outfitted module with all the necessary equipment required for complete functional capability. It will be able to accommodate generic and user supplied equipment such as: furnaces, crystal slicers, photo lab provisions, x-ray diffraction equipment and microscopes.

SS-SPEC-0003 LOGISTICS ELEMENTS SPECIFICATION

The Logistics Elements provide pressurized and unpressurized carriers for transporting equipment and supplies between the ground and orbit; and for the temporary on-orbit storage of station consumables, waste products and customer equipment.

The Logistics Elements pressurized and unpressurized carriers will be used to satisfy the logistics requirements of the Space Station. The carriers support the transport of four generic classes of cargo: pressurized cargo, unpressurized cargo, propellants and fluids.

SS-SPEC-0004 AIRLOCK SPECIFICATION

The Airlock provides a means for the transfer of crew and equipment between pressurized and unpressurized zones. This general purpose EVA airlock will include WP-01 provided equipment which includes the following:

- Primary and secondary structure
- Meteoroid Protection
- Hatches, windows and hatch mechanisms
- Utility distribution
- Tools/supplies support
- Outfitting

SS-SPEC-0005 HYPERBARIC AIRLOCK SPECIFICATION

The Hyperbaric Airlock will withstand five atmospheres of internal pressure to support the treatment of decompression sickness. The Hyperbaric Airlock structure, pressurization/depressurization, utilities, distribution and outfitting is the responsibility of WP-01.

SS-SPEC-0006 RESOURCE NODES SPECIFICATION

The Resource Nodes provide an intersection between Space Station pressurized modules for the passage of personnel, equipment and utilities. They are pressurized structures which may be connected to a pressurized module, pressurized attached payloads, airlocks and the Orbiter via docking/berthing mechanisms. Resources Nodes may also accommodate viewing, station storage and some user equipment, but will not be outfitted at IOC.

SS-SPEC-0100 HABITATION MODULE SPECIFICATION

The Habitation Module accommodates crew habitation and station operations. It includes systems such as: crew quarters, personal hygiene systems, galley/wardroom, station command and control work stations, a general purpose work bench, crew personal storage, waste collection and management provisions, recreational provisions, dishwasher, clothes washer and dryer.

The WP-01 specification tree is shown in Figure 2.1-1.

2.1.7 Preliminary Design Data

The following preliminary design items can be found in DR-02 (13.2f).

Layouts

Drawings

Mass properties

WP Element and Subsystem Performance Data

Subsystem Definition

Master Equipment Lists

Refurbishment Activities List

Risk Assessments

Alignment

Contamination and Other Analyses Results

2.2 Man Tended

2.2.1 Man Tended Strategy and Approach

A Man Tended Space station will be a key evolutionary step towards a permanently manned station. Work Package 01 strategy has been to emphasize the configuration evolutionary process keying in on Man Tended options and capability. Key elements in the approach to satisfying the Man Tended study have included: (1) determining Man Tended Approach (MTA) impacts on experiment cost and productivity; (2) defining a minimal but productive Man Tended Configuration and operational scenario; (3) developing sensitivity parameters and (4) identifying additional costs that might evolve from developing a Man Tended station into a permanently manned station.

2.2.2 Man Tended Study Flow

The Man Tended study effort paralleled and received inputs impact from the permanently manned station study. Design trades, analyses and evaluations were performed on the Level B provided Man Tended reference configuration. A key result of this effort was the identification of parametric cost, risk, performance and capability data to support the Man Tended station design analysis.

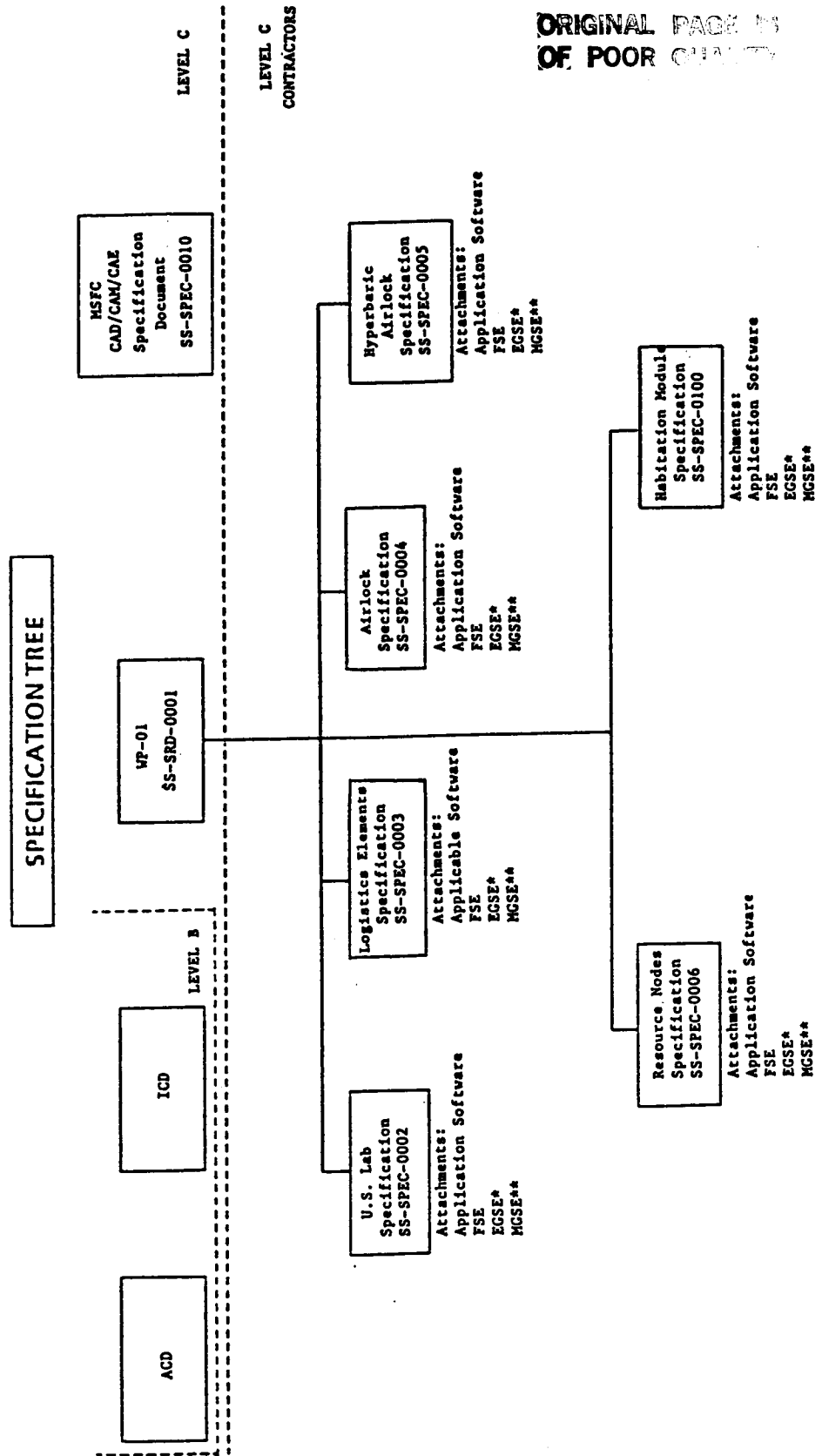


FIGURE 2.1-1 SPECIFICATION TREE

Attachment Legend:

*EGSE Attachment contains appendices for Simulators, Integration Test Sets and Unit Test Sets and includes an attachment of EGSE Application Software.

**MGSE Attachment contains appendices for Handling, Transportation, Checkout and Test, Servicing, and Accessibility equipment.

FIGURE 2.1-1 SPECIFICATION TREE

2.2.3 Man Tended Results

Although the Man Tended configuration has been determined to be a reasonable step in the evolution of a manned station, study results show the MTA would be significantly less productive for a higher total cost. Findings supporting this conclusion are summarized as follows: (1) MTA allows for a deferral of funding (18%), yet at a 30% higher total cost; (2) only one-third of the initial necessary experimental results would be attainable utilizing the MTA station; (3) the cost per experiment would be higher for the MTA station and (4) MTA would be a reasonable step in the evolution of a Permanently Manned Station (PMS) if duration of MTA is short.

A significant portion of the Phase B effort was dedicated toward the Man Tended option analysis, evaluation, trades and overall concept study. Specific Man Tended approaches are covered in detail in deliverables under DR-02, Preliminary Analysis and Design Document. A complete summary of the Man Tended study is contained in document D483-50066-1, Man Tended Approach (MTA) IRR Report (WP01 Input), which is provided as part of this supplemental DR-15 submittal.

2.3 Automation and Robotics

Effective implementation of Automation and Robotics (A&R) has the potential to increase Space Station productivity while significantly reducing operating costs.

2.3.1 Introduction

The Congress, in Public Law 98-371, established a requirement for the Space Station Program to study the development and application of advanced automation technology not in use on existing spacecraft. In response to this public law, NASA formed the Advanced Technology

Advisory Committee (ATAC). This committee was tasked to provide NASA with recommendations as to promising areas of development in A&R and to report their findings to Congress. These recommendations were used as guidelines in the development of the Space Station A&R Plan (DR-17).

As part of the ATAC effort, BAC strongly supported and contributed to the work of the University and Industry Panel, lead by the California Space Institute (Calspace), which provided A&R candidate recommendations and technology evaluations. In fact, BAC's noncontractual volunteered support provided significant additional study breadth, especially in the area of operator systems interfaces. Additionally, our independent technology assessment provided the ATAC invaluable support in their recommendations.

2.3.2 Scope

Application candidates identified in this document are limited to those arising out of WP-01 areas of responsibility.

2.3.3 Approach

In our preliminary report, dated June 1986, we identified a large number of A&R candidates, performed a parallel technology assessment, and established the criteria to be used for candidate screening. The remainder of the sub-tasks have now been completed through a first iteration and are covered within this report. From the initial large set of candidates a reduced set was selected for further study. From the reduced set an implementation plan has been prepared and can be found in Boeing Document, D483-50055-1 (DR-17).

2.3.4 Selection Criteria

The criteria employed are as follows:

- Productivity
- Crew and station safety
- Autonomy
- Human limitations
- Technology transfer
- Cost

2.3.4.1 Description of Criteria

Space Station resources required for operations are expected to be critical and limited. It is very important to make the work as productive as possible. A&R technology will enable the crew to function in a supervisory mode, making their work more productive.

Time consuming tasks are prime candidates for automation because on-orbit man hours are costly. For example, it is important that inventory control is accomplished, but it is time consuming if done manually. An on-board, computerized inventory management system can eliminate manual inventorying and simplify the task of searching for equipment and material at the same time.

A smart man-machine interface is required on the station because the crew must interact efficiently with automated devices. A vocal interface such as an Advanced Conversational Operator System Interface would enhance crew productivity. It uses conversational style spoken language as the primary operator system interface. The interface is a "natural" interface (it is the way humans are trained to communicate between ourselves) and the crew can operate or perform other tasks while interfacing with this system. The user can interactively query the sys-

tem for data while performing a primary function. For example, when a crewmember is performing OMV docking, his hands will be engaged in operating the maneuvering controls. If he has to obtain additional data (i.e., rate and distance), he would have to remove one hand from the controls to input the query on a keyboard. With a vocal interface he can voice query the system for the data he needs, leaving his hands available to continue controlling the OMV.

Using an intelligent data management system, computer graphics and speech synthesis, an integrated system can be developed to display information to the crew in a condensed, visually informative manner. Systems which will accomplish this are the Integrated Training System.

2.3.4.2 Crew and Station Safety

Crew safety has been a critical consideration in any manned space project and will continue to be so with the Space Station Program. A&R will support safety requirements to ensure the integrity of the Space Station.

Safety related tasks involve hazardous materials handling, large mass material handling and a need for EVA activities. Handling fuels and some on-board experiments fall in this category. Candidates such as the Module Safety Advisor were selected primarily because the system can identify/predict hazards and recommend appropriate crew safety countermeasures. It is capable of providing an explanation for its action, so the crew can develop confidence in using the system.

2.3.4.3 Ground Autonomy

Current space operations rely heavily on large ground support teams using many man-hours. One of the main design

guidelines for the Space Station is to be operationally autonomous. Operational autonomy is also a safeguard against emergency situations where failures or natural phenomena will disable communications.

Many A&R systems are needed to achieve autonomy from ground operations. Expert systems such as the Fault Prediction/Trend Analysis are needed to perform many monitoring and control functions requiring complex status analysis and automated decision making. A&R help relieve the added load on the on-board system imposed by autonomy. The automatic devices are allowed to make lower level decisions to unload as much work as possible. The crew can be left undisturbed to perform their missions.

2.3.4.4 Human Limitations

"Human limitation" refers to four basic factors,

- (1) Reaction time
- (2) Task workload
- (3) Monitoring capability
- (4) Strength /precision

Human reactions are not adequate to effectively deal with many real-time events. Candidates such as the Intelligent controller would automatically perform operations which the crew could not accomplish quickly enough.

Task workload in a manually operated system involves monitoring gauges and operating switches. A human has limits on the amount of work he can do. A&R technology relieves the workload, allowing the crew to do the work best suited for humans.

The monitoring capability of humans also has a limit, the crewmember will begin to inadequately scan or monitor at some high rate of data input. The ability of machines to perceive data outside the range of human sensory capability is another important criteria for automation. Such tasks includes detecting small particles, infrared, microwave radiation, or atmospheric contaminants such as CO₂.

Many of the Space Station functions impose requirements that are beyond the strength capabilities of EVA astronauts. Tasks that require handling of large payloads and OMV berthing are candidates for handling by expert robotic systems. The inversely proportional relationship between strength and precision indicates that gross movements of massive objects may be accomplished by robots and final, precise adjustments performed by humans. This allows lower cost design of the robots because it removes the need to design a device which has both great strength and precise motion.

2.3.4.5 Technology Transfer

A&R applications which could benefit terrestrial technology and commercial industry should be considered for development. Space Station A&R applications would enhance the Nation's technical and scientific base leading to more productive industry on Earth.

History has shown that there is a close link between advances in technology and the strength of the U.S. economy. The Space Station Program can provide the new technology that will keep the U.S. economy in a competitive position in the world. Tasks such as remote inspection and automatic systems monitoring occur in many fields. The A&R development for such systems

are worthwhile candidates for technology transfer.

Development of expert system applications for the Space Station will greatly affect technology on Earth. Expert system technology such as the Module Safety Advisor can be transferred to safety sensitive systems such as nuclear power plants.

In the area of robotics, technology can be transferred for terrestrial applications, which in turn can increase U.S. employment. A summary statement from a study done by a Congressional subcommittee and the Office of Technology Assessment states: "In the long run, industrial robots should lead to improved working conditions, higher real wages and the creation of more jobs." The development of dextrous manipulators, smart sensors, voice control, operator system interfaces, applications software and integration of expert systems in real time will be key advances in the practical large scale use of Automation and Robotics in commercial industry.

2.3.4.6 Cost

The importance of cost as a selection criteria for A&R candidates becomes apparent when one considers Space Station as a design to cost program.

There are two major categories of cost. The first is nonrecurring cost. This is a one time cost, such as tooling cost, the cost for research and development, the cost to design the system, and manufacturing and testing cost. The second element of cost is the recurring cost, commonly referred to as operations cost. This occurs on a continuous basis and pays to maintain and operate a system.

The selection of a candidate must be based on non-recurring and recurring cost, because an A&R candidate might

have a low initial cost but have a high failure rate.

Cost will be the dominant criteria in Boeing's A&R trade studies. This is due to the fact that this is a design to cost program and trade studies are cost/benefit analyses.

The preliminary candidates selected for further study and subsequently for inclusion in the plan were basically those with a high benefit rating. Realignment of work package boundaries eliminated some candidates with a high rating. In some cases we chose to combine similar functions from different work package elements. The selected set of candidates is shown in Figure 2.3-1. These candidates are discussed in detail in Boeing Document D483-50055-1 Rev B (DR-17) dated Oct. 31, 1986 - A&R Plan.

A technology assessment has been performed for each candidate in which expected dates for the availability of the required advancements are estimated. Costs have been estimated using the RCA Price H model for hardware, and estimates of the number of lines of code and number of rules for software. A crew workload model has been built to evaluate the effects of automation on crew utilization. Based on Skylab experience and driven by crew size, number of pressurized U.S. modules and external payloads, this modeling approach makes it possible to assess the impact of automation during a growth scenario. The on-orbit activity time percentages which drive the workload model are shown in Figure 2.3-2 and the workload evaluation methodology is shown in Figure 2.3-3. A time-phased implementation plan has been formulated and hook and scar requirement for the IOC station identified.

CANDIDATE	WP-01 ELEMENTS						
	STRUCTURE	TCS	EPS (Int.)	ECLSS	OMV ACCOM	LOGISTIC ELEMENT	MTL LAB
Software Application Generator		X	X	X	X	X	X
Design Knowledge Database	X	X	X	X	X	X	X
Advanced Conversational OSI		X	X	X	X	X	X
Module Safety Advisor	X	X	X	X			
Intelligent Tape Recorder	X	X	X	X	X		X
EVA Inspector Robot	X				X		
Manned EVA Teleoperator	X						
Smart Front End					X		
Integrated Maintenance Trainer	X	X	X	X	X	X	X
Mobile Intelligent Dexterous Robot	X				X	X	
Autonomous Controller	X	X	X	X	X	X	X
State Estimator	X	X	X	X			X
Subsystem Monitor/Statusing System	X	X	X	X	X	X	X
Fault Prediction/Trend Analysis	X	X	X	X	X	X	X
Fault Manager	X	X	X	X	X	X	X
Integrated Controller	X	X	X	X	X	X	X
FMEA Assistant	X	X	X	X	X	X	X
Operation and Maintenance Scheduler						X	
Inventory Management System	X	X	X	X	X	X	X
Robot Friday					X	X	X
MTL Experiment Monitor and Control							X

FIGURE 2.3-1 CANDIDATE APPLICATION WP-01 ELEMENTS

FIGURE 2.3-1 CANDIDATE APPLICATION WP-01 ELEMENTS

Percentages based on total
on-orbit time (for one team)
 $3 \text{ crew} \times 24 \text{ hours} \times 90 \text{ days} = 6,480$
hours

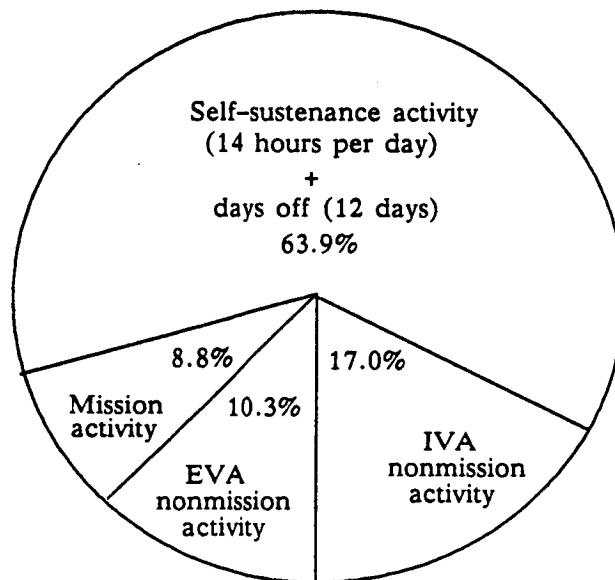


FIGURE 2.3-2 ON-ORBIT ACTIVITY TIME PERCENTAGES

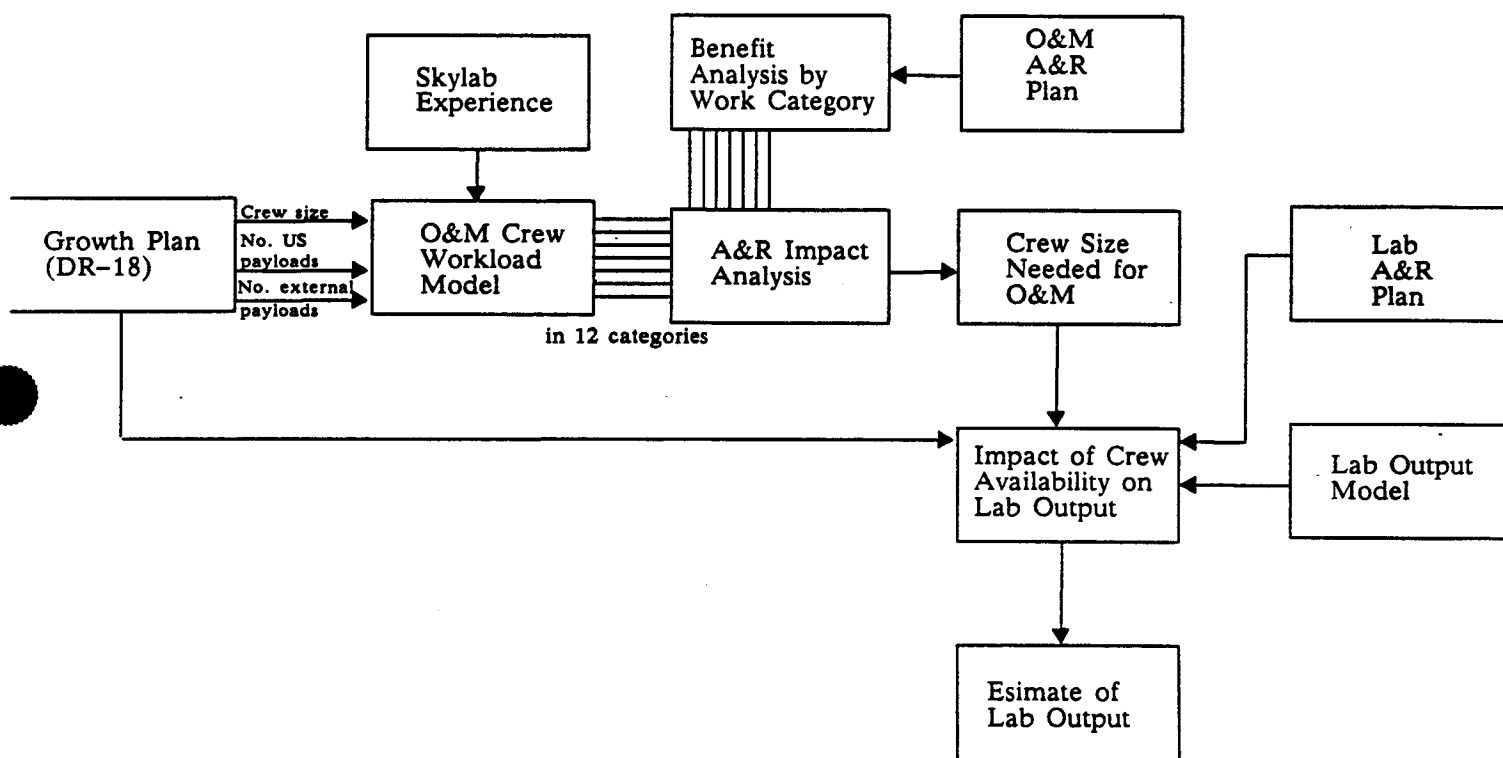


FIGURE 2.3-3 METHODOLOGY FOR EVALUATING CREW UTILIZATION OF A&R CANDIDATES

2.4 Space Station Evolutionary Process

Included here is a brief summary of the Space Station Evolutionary process.

2.4.1 Contract Start Date (C&D) Configuration

At contract start date the configuration of the station was:

- a. Gravity Gradient "Power Tower"
- b. Vertical Racetrack pattern
- c. Four US Modules
 - two Habitat
 - two Laboratory
- d. Two Airlocks
 - 1 Hyperbaric
 - 1 EVA Airlock
- e. Modules were at the base of the Tower
- f. Photovoltaic Power was the reference power sources

2.4.2 RUR-1 Configuration

At RUR-1 the configuration of the Station remained basically unchanged.

2.4.3 RUR-2 Configuration

At RUR-2 the configuration of the Station had evolved to:

- a. Gravity Gradient "Power Tower"
- b. Twin Keel
- c. Horizontal "Figure - 8" pattern
- d. Four US Modules
 - 2 Habitat
 - 2 Laboratory
- e. Six Nodes

f. Three Tunnels

g. Two Airlocks

- 1 Hyperbaric Chamber
- 1 EVA Airlock

h. Modules were located below the transverse beam

i. Photovoltaic Power

2.4.4 IRR Configuration

At IRR, the configuration of the Station had evolved to:

- a. 1 balanced "Power Tower"
- b. Horizontal "Figure - 8" pattern
- c. Four US Modules
 - 2 Habitat
 - 2 Laboratory
- d. Six Nodes
- e. Three Tunnels
- f. Two Airlocks
 - 1 Hyperbaric
 - 1 EVA Airlock

g. Modules were located above the transverse beam

h. Photovoltaic Power

2.4.5 SRR Configuration

At SRR, the Station configuration had evolved to:

- a. Inertial balanced "Power Tower"
- b. Horizontal "Figure - 8" pattern
- c. Two US Modules
 - 1 Habitat
 - 1 Laboratory

- d. Four Nodes
- e. Two Tunnels
- f. Two Airlocks
 - 1 Hyperbaric
 - 1 EVA Airlock
- g. Module pattern above transverse beam
- h. Photovoltaic/Solar Dynamic Power

2.4.6 Post SRR Configuration

Subsequent to SRR Evolutionary cycles continued and the configuration discussed in Section 6 is:

Inertial balanced "Power Tower" Horizontal "Figure - 8" pattern
Two US Modules

One Habitat

One Laboratory

Two Resource Nodes

Two Airlocks

One Hyperbaric

One EVA Airlock

Module pattern above transverse beam
Photovoltaic/Solar Dynamic Power

2.5 Software Development

This section will deal with software in two parts 1) Interface definition occurring for WP-01 with some data flow diagrams and 2) Boeing's view of them.

2.5.1 External and Internal I/F Definition

This section identifies the functional interfaces occurring within WP-01 and interfaces between WP-01 and other work packages. To identify the interfaces, a top

down structural approach was utilized. A hierarchy of data flow diagrams DFD's were created, identifying functions to be performed and the data required to perform them. Each level downward in the hierarchy shows a more detailed version, breaking down the "parent" function and data flows into subfunctions and sub-data flows. The DFDs are followed by a data dictionary describing the contents of the data flows.

These DFD's are shown on Figure 2.5-1 and 2.5-2 and the associated dictionary is shown in Table 2.5-I.

2.5.2 Software Support Environment

The central objectives of the Software Support Environment (SSE) are the production of less expensive and more reliable software - and in less time than has historically been the case. It must be emphasized that the production of software involves an integrated discipline ranging over the entire product lifetime, from requirements to retirement of the programming system. The discipline alluded to must be described, encouraged and ultimately enforced by an appropriate Software Engineering Program consisting of standards, procedures and tools - as well as a programming and managerial workforce trained in the effective use of the relevant parts of the program.

The standards and procedures under which software development occurs are, in many ways, the most critical of the Software Engineering program elements mentioned. These will detail a well-reasoned set of administrative and technical policies and constraints under which the programming task must take place. The value of an intelligently formulated programming discipline of standards and procedures has been repeatedly demonstrated within Boeing and elsewhere. Errors, particularly

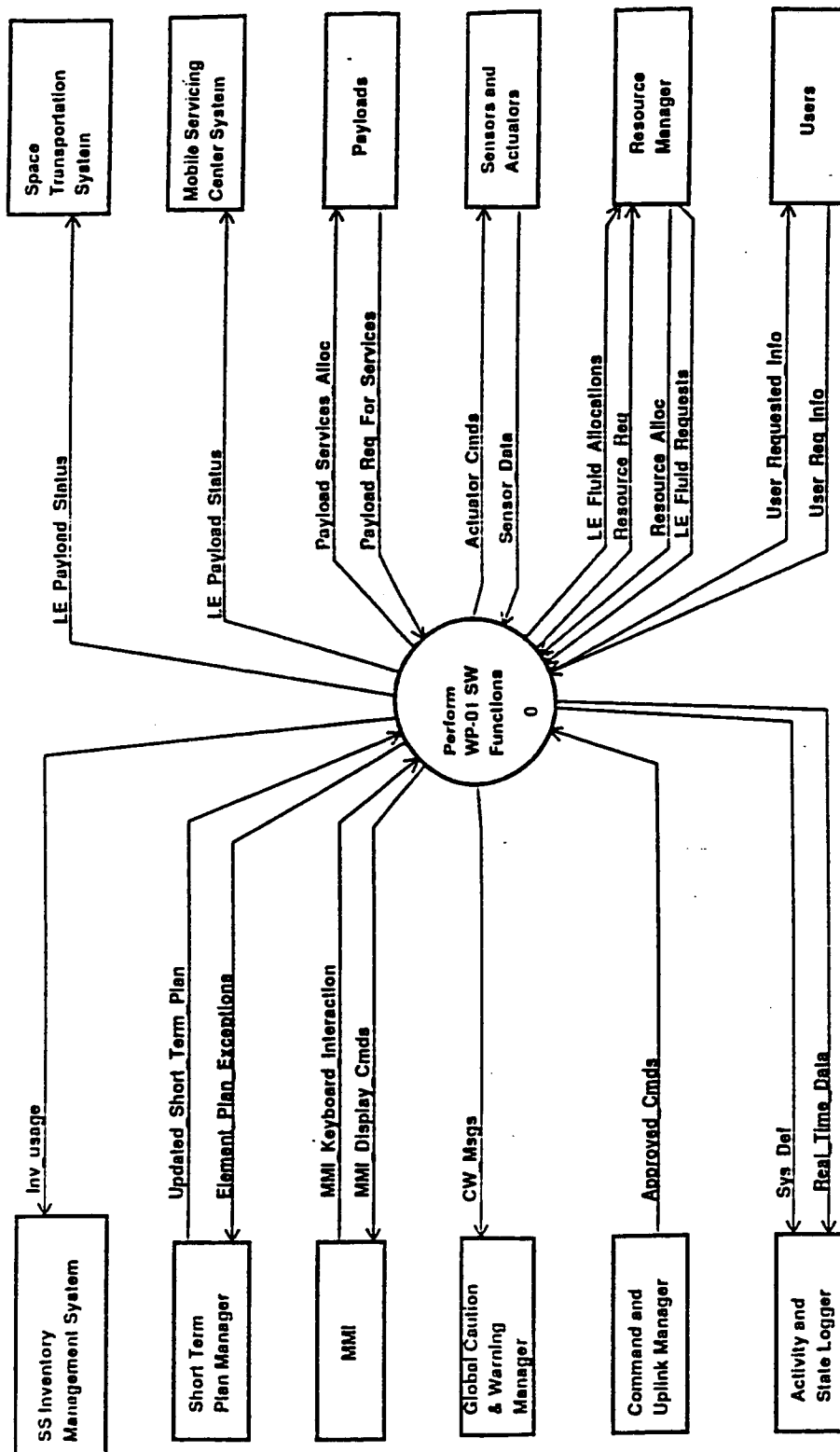
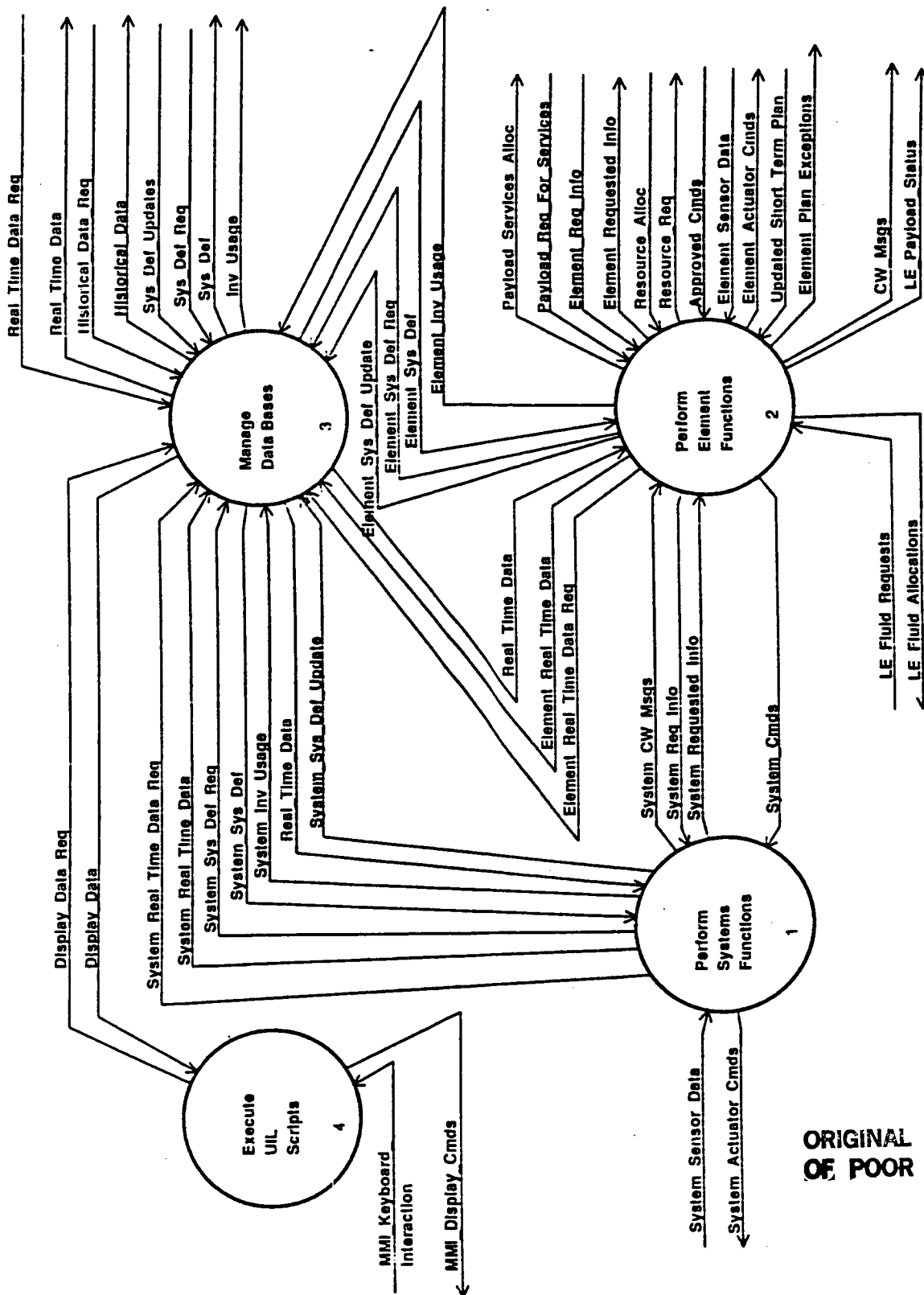


FIGURE 2.5-1 DATA FLOW DIAGRAM



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FIGURE 2.5-2 DATA FLOW DIAGRAM

TABLE 2.5-I DFD DICTIONARY

(Table continues and concludes on sheet 38)

NAME:

92

TITLE:

Manage Resources

INPUT/OUTPUT:

Comm_Utility_Req : data_in
Comm_Utility_Alloc_And_Data : data_out
Thermal_Utility_Req : data_in
Thermal_Utility_Alloc_And_Data : data_out
Power_Allocations : data_out
ECLSS_Utility_Req : data_in
ECLSS_Utility_Alloc_And_Data : data_out
HSO_Utility_Req : data_in
HSO_Utility_Alloc_And_Data : data_out
Log_Utility_Req : data_in
USL_Utility_Req : data_in
USL_Utility_Alloc_And_Data : data_out
SM_Utility_Req : data_in
SM_Utility_Alloc_And_Data : data_out
Utility_Req : data_out
RM_Short_Term_Plan : data_in
RM_Activity_And_State_Info : data_out

Utility_Alloc_And_Data : data_in
RM_Cmds : data_in
Log_Utility_Alloc_And_Data : data_out

BODY:

This process manages power, thermal rejection, ECLSS, and communication resources. When a module/subsystem requires a resource, it makes a request to the resource manager. The resource manager determines the availability of the resource, sends the appropriate commands to the affected resource control processes, and answers the request with the amount of resource to be granted. This process has a concept of priority, and has the ability to reduce the amount of resource allocated to a module/subsystem if something of a higher priority requests that resource. This process also has knowledge of the short term plan, and takes into consideration the resource requirements expected in the near future when granting resource requests.

Activity_And_State_Info (dataflow) =
[ECLSS_Activity_And_State_Info | Power_Activity_And_State_Info |
Thermal_Activity_And_State_Info | Comm_Activity_And_State_Info |
HSO_Activity_And_State_Info | Log_Activity_And_State_Info |
USL_Activity_And_State_Info | SM_Activity_And_State_Info |
RM_Activity_And_State_Info].

Actuator_Cmds (dataflow) =
[ECLSS_Actuator_Cmds | Power_Actuator_Cmds | Thermal_Actuator_Cmds |
Comm_Actuator_Cmds | HSO_Actuator_Cmds | LE-FMS_Actuator_Cmds |
USL_Actuator_Cmds | SM_Actuator_Cmds].

Approved_Cmds (dataflow) =
* Approved commands from the command manager to be sent to appropriate
subsystem/element *
[ECLSS_Cmds | Power_Cmds | Thermal_Cmds | Comm_Cmds | HSO_Cmds |
Log_Cmds | USL_Cmds | SM_Cmds | RM_Cmds].

Comm_Activity_And_State_Info (dataflow) =
TBD.

Comm_Actuator_Cmds (dataflow) =
TBD.

Comm_Cmds (dataflow) =
TBD.

Comm_CW_Msgs (dataflow) =
not-defined.

Comm_Req_Info (dataflow) =
TBD.

Comm_Requested_Info (dataflow) =
TBD.

Comm_Requests (dataflow) =
TBD.

Comm_Sensor_Data (dataflow) =
TBD.

Comm_Short_Term_Plan (dataflow) =
TBD.

Comm_Test_Response (dataflow) =
TBD.

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DFD Dictionary

Comm_Test_Stimulus (dataflow) =
"TBD".

Comm_Utility_Alloc_And_Data (dataflow) =
"not-defined".

Comm_Utility_Req (dataflow) =
"TBD".

CW_Msgs (dataflow) =
• Caution and warning messages from the elements and subsystems to the global caution and warning manager (part of OMA) *
[ECLSS_CW_Msgs | Power_CW_Msgs | Thermal_CW_Msgs | Comm_CW_Msgs | HSO_CW_Msgs | Fluid_CW_Msgs | USL_CW_Msgs | SM_CW_Msgs].

ECLSS_Activity_And_State_Info (dataflow) =
"Measurement values obtained from ECLSS sensor readings".

ECLSS_Actuator_Cmds (dataflow) =
THC_Actuator_Cmds
+ ARC_Actuator_Cmds
+ WRM_Actuator_Cmds
+ FDS_Actuator_Cmds
+ WM_Actuator_Cmds

ECLSS_Cmds (dataflow) =
THC_Cmds +
ARC_Cmds +
WRM_Cmds +
FDS_Cmds +
WM_Cmds

ECLSS_CW_Msgs (dataflow) =
ECLSS_CW_Messages
+ ECLSS_Critical_Failures

ECLSS_Inv_Usage (dataflow) =
"Inventories used by ECLSS- ARC and WRM are the primary users of inventories".

ECLSS_Req_Info (dataflow) =
ECLSS_Monitor_Req
+ ECLSS_Request_Info
+ ECLSS_Range_Limits

ECLSS_Requested_Info (dataflow) =
- ECLSS_Requested_Data+ECLSS_Monitor_Data

ECLSS_Sensor_Data (dataflow) =

DFD Dictionary

Includes all sensor measurements from all ECLSS subsystems

ECLSS_Short_Term_Plan (dataflow) =
Schedules and priorities for ECLSS operations.

ECLSS_Test_Response (dataflow) =
ARC_Test_Response +
FDS_Test_Response +
THC_Test_Response +
WM_Test_Response +
WRM_Test_Response

ECLSS_Test_Stimulus (dataflow) =
ARC_Test_Stimulus +
FDS_Test_Stimulus +
THC_Test_Stimulus +
WM_Test_Stimulus +
WRM_Test_Stimulus

ECLSS_Utility_Alloc_And_Data (dataflow) =
Utilites and related information allocated to ECLSS.

ECLSS_Utility_Req (dataflow) =
ECLSS request for utilities based on ECLSS subsystem requirements.

Fluid_CW_Msgs (dataflow) =
[[Fluid_CW_Alarms | Fluid_CW_Notice]]

FM_Activity_And_State_Info (dataflow) =
not-defined.

FMS_Power_Request (dataflow) =
FMS_Power_Required + Required_Time_Period

HSO_Activity_And_State_Info (dataflow) =
sensor data, trend data.

HSO_Actuator_Cmds (dataflow) =
commands to HAB actuators.

HSO_Cmds (dataflow) =
- *commands to HSO functions*.

HSO_CW_Msgs (dataflow) =

*the subset of h/w and s/w responses
that indicate something has gone
wrong*.

HSO_Inv_Usage (dataflow) =
report of HSO inventory usage.

HSO_Req_Info (dataflow) =
request for displays.

HSO_Requested_Info (dataflow) =
HAB_Sensor_Data * + static/dynamic displays*

HSO_Sensor_Data (dataflow) =
data from HSO sensors.

HSO_Short_Term_Plan (dataflow) =
short term plan for HSO.

HSO_Test_Response (dataflow) =
hardware and software responses to stimulus.

HSO_Test_Stimulus (dataflow) =
commands to hardware, continuity checks to actuators.

HSO_Utility_Alloc_And_Data (dataflow) =
responses to utility requests.

HSO_Utility_Req (dataflow) =
ask EPS for power, FMS for fluids, etc..

Inv_usage (dataflow) =
* Usage of consumable inventory (fluids, etc.)
[ECLSS_Inv_Usage | Thermal_Inv_Usage |
HSO_Inv_Usage | Log_Inv_Usage | USL_Inv_Usage].

LE-FMS_Actuator_Cmds (dataflow) =
Fluid_Pressure_Regulator_Actuation +
Fluid_Temperature_Regulator_Actuation +
Fluid_Transfer_Actuator_Data

LE_Payload_Status (dataflow) =
LE_Power_Status + LE_AC_Status + TSS_Status

*Status of specific cargo that requires
continuous monitoring during transport. The
data can be for the NSTS or the MSCS. No other element

requires continuous monitoring during transport.
AC - Active Cargo
TSS - Transport Status System
LE - Logistics Element*.

Log_Activity_And_State_Info (dataflow) =
[LE_Transport_Mode | LE-Fluid_Status]

Log_Cmds (dataflow) =
[LE-IMS-User_Commands | LE-Fluid_Commands]

Log_Inv_Usage (dataflow) =
[LE-IMS_Reorder_List | LE-IMS_Responses]

Log_Req_Info (dataflow) =
LE-IMS-User_Requests

Log_Requested_Info (dataflow) =
[LE-IMS_Reorder_List | LE-CG_Data | LE-IMS_Responses |
LE_Transport_Mode | LE-Fluid_Status | LE_Payload_Status]

Log_Sensor_Data (dataflow) =
[LE-IMS_Sensor_Data | LE-FMS_Sensor_Data]

Log_Short_Term_Plan (dataflow) =
{Fluid_ID + Fluid_Usage_Schedule}

Log_Test_Response (dataflow) =
[LE_Fluid_Sensor_Test_Responses | LE_Fluid_Equipment_Test_Responses]

Log_Test_Stimulus (dataflow) =
[FMS_Sensor_Test_Stimulus | FMS_Equipment_Test_Stimulus]

MSCS-LE_Payload_Req_For_Status (dataflow) =
MSCS-LE_Power_Request + LE_AC_Status_Request + TSS_Mode

*Monitor status request of the pressurized
logistics element cargo that requires continuous
life support, power, and/or other monitoring
during transport. The data can be for the NSTS or the MSCS.
LE - Logistics Elements
AC - Active Cargo
TSS - Transport Status System*.

Payload_Req_For_Services (dataflow) =
Payload_Requestor_ID + Requests_For_Utility_Services.

Payload_Services_Alloc (dataflow) =
Payload_Requestor_ID + Services_Allocated +
Schedule_of_Allocation

09.16.86.SC.

Power_Activity_And_State_Info (dataflow) =
{Checked_Power_Status + Condition +
Switch_ID + Switch_Position}

Power_Actuator_Cmds (dataflow) =
[Power_Distribution_Actuator_Commands | Loads_Actuator_Commands]

Power_Allocations (dataflow) =
Power_Available + Power_Period

Power_Cmds (dataflow) =
[LE_Transport_Mode | Power_Distribution_Commands_and_Requests]

Power_CW_Msgs (dataflow) =
[Load_CW_Notice | Power_CW_Notices]

Power_Req_Info (dataflow) =
[Power_User_Distribution_Changes | Power_User_Load_Data |
Power_User_Load_Schedule | Power_CW_Limits]

Power_Requested_Info (dataflow) =
[Power_User_Load_Responses | Power_User_Load_Schedule_Responses]

Power_Sensor_Data (dataflow) =
[Input_Power_Sensor_Data | Power_Limit_Sensor_Data |
Distribution_Power_Sensor_Data]

Power_Short_Term_Plan (dataflow) =
Load_ID + Schedule_On_Time + Load_Op_Time

Power_Test_Response (dataflow) =
[Power_Test_Status_Response | Power_Test_Loads_Response]

Power_Test_Stimulus (dataflow) =
[Power_Sensor_Test_Stimulus | Power_Equipment_Test_Stimulus]

RM_Activity_And_State_Info (dataflow) =
* Historical data from resource management process consisting
of messages sent, messages received, etc. *

RM_Short_term_Plan (dataflow) =
•TBD•

Sensor_Data (dataflow) =
[ECLSS_Sensor_Data | Power_Sensor_Data | Thermal_Sensor_Data |
Comm_Sensor_Data | HSO_Sensor_Data | Log_Sensor_Data |
USL_Sensor_Data | SM_Sensor_Data].

SM_Activity_And_State_Info (dataflow) =
"sensor data, trend data".

SM_Actuator_Cmds (dataflow) =
[SM-Hatch_Actuator_Commands|SM-Berthing_Mechanism_Actuator_Commands].

SM_Cmds (dataflow) =
[SM-Hatch_Command|SM-Berthing_Mechanism_Command].

SM_CW_Msgs (dataflow) =
"the subset of h/w and s/w responses
that indicate something has gone
wrong".

SM_Req_Info (dataflow) =
"requests for displays".

SM_Requested_Info (dataflow) =
SM_Sensor_Data " + static/dynamic displays".

SM_Sensor_Data (dataflow) =
[SM-Hatch_Sensor_Data|SM-Berthing_Mechanism_Data].

SM_Test_Response (dataflow) =
"hardware and software responses
to stimulus".

SM_Test_Stimulus (dataflow) =
"commands to hardware, continuity checks to actuators and sensors".

SM_Utility_Alloc_And_Data (dataflow) =
"responses to utility requests".

SM_Utility_Req (dataflow) =
"utility requests; e.g. power to run motors, ECLSS to
repressurize docking mechanism".

STS-LE_Payload_Req_For_Status (dataflow) =
STS-LE_Power_Request + LE_AC_Status_Request + TSS_Mode

*Monitor status request of the pressurized logistics element cargo that requires continuous life support, power, and/or other monitoring during transport. The data can be for the NSTS or the MSCS.
LE - Logistics Elements
AC - Active Cargo
TSS - Transport Status System*.

Test_Response (dataflow) =
[ECLSS_Test_Response | Power_Test_Response | Thermal_Test_Response | ComX
m_Test_Response |
HSO_Test_Response | Log_Test_Response | USL_Test_Response | SM_Test_ResX
ponse].

Test_Stimulus (dataflow) =
[ECLSS_Test_Stimulus | Power_Test_Stimulus | Thermal_Test_Stimulus |
Comm_Test_Stimulus | HSO_Test_Stimulus | Log_Test_Stimulus |
USL_Test_Stimulus | SM_Test_Stimulus].

Thermal_Activity_And_State_Info (dataflow) =
"TBD".

Thermal_Actuator_Cmds (dataflow) =
"TBD".

Thermal_Cmds (dataflow) =
"TBD".

Thermal_CW_Msgs (dataflow) =
"not-defined".

Thermal_Inv_Usage (dataflow) =
"TBD".

Thermal_Req_Info (dataflow) =
"TBD".

Thermal_Requested_Info (dataflow) =
"TBD".

Thermal_Sensor_Data (dataflow) =
"not-defined".

Thermal_Short_Term_Plan (dataflow) =

"TBD".

Thermal_Test_Response (dataflow) =
"TBD".

Thermal_Test_Stimulus (dataflow) =
"TBD".

Thermal_UTILITY_Alloc_And_Data (dataflow) =
"TBD".

Thermal_UTILITY_Req (dataflow) =
"TBD".

TSS_EPS_Status (dataflow) =
LE-EPS_Caution_and_Warning_Notices +
Power_Status +
User_Load_Responses +
User_Load_Schedule_Responses

Updated_Short_Term_Plan (dataflow) =
• "Final" version of short term plan, sent to systems/elements •
ECLSS_Short_Term_Plan + Power_Short_Term_Plan + Thermal_Short_Term_Plan +
Comm_Short_Term_Plan + HSO_Short_Term_Plan + Log_Short_Term_Plan +
USL_Short_Term_Plan + RM_Short_Term_Plan.

User_Req_Info (dataflow) =
• User initiated request for info from subsystem/element •
[ECLSS_Req_Info | Power_Req_Info | Thermal_Req_Info | Comm_Req_Info |
HSO_Req_Info | Log_Req_Info | USL_Req_Info | SM_Req_Info].

User_Requested_Info (dataflow) =
• Info sent to users from subsystem/element on request •
[ECLSS_Requested_Info | Power_Requested_Info | Thermal_Requested_Info |
Comm_Requested_Info | HSO_Requested_Info | Log_Requested_Info |
USL_Requested_Info | SM_Requested_Info].

USL_Actuator_Cmds (dataflow) =
USL_Actuator_ID + USL_Actuator_Activation_Data

"09.24.86.SC".

USL_Cmds (dataflow) =
User_ID + User_Commands_to_USL_Subsystems

"09.24.86.SC".

USL_CW_Msgs (dataflow) =
USL_Caution_and_Warning_Advisories + Originator_ID

08.28.86.

USL_Inv_Usage (dataflow) =
Time_Stamp_ID + User_ID + Inventory_Number +
Item_Name + {New_Location}

USL_Req_Info (dataflow) =
[Crew_ID | GRound_User_ID] + Request_ID + USL_Information_Request

09.24.86.SC.

USL_Requested_Info (dataflow) =
[Crew_Requestor_ID | Ground_Requestor_ID] + Request_ID + USL_Requested_InX
formation

09.24.86.SC.

USL_Sensor_Data (dataflow) =
USL_Sensor_ID + Formatted_USI_Sensor_Reading

09.24.86.SC.

USL_Short_Term_Plan (dataflow) =
Scheduled_Task_ID + Schedule_For_Task

09.24.86.SC.

USL_Test_Response (dataflow) =
Tested_System_ID + Formatted_Test_Results

09.24.86.SC.

USL_Test_Stimulus (dataflow) =
USL_system_to_Test_ID + Test_requestor_ID + USL_System_Test_Procedures

09.24.86.SC.

USL_Utility_Alloc_And_Data (dataflow) =
USL_Task_ID + USL_Utility_Allocation_to_Task +
Allocation_Schedule

09.24.86.SC.

USL_Utility_Req (dataflow) =
Requestor_ID + USL_Utility_Request

09.24.86.SC.

Utility_Alloc_And_Data (dataflow) =

- Utility Allocation Verification from external utility sources (Power, EX CLSS, Thermal, and Communication) to resource manager •
- Resource_ID + Quantity + Units.

Utility_Req (dataflow) =

- Requests for external resources (Power, ECLSS, Thermal, CommunicationsX) from resource manager •
- Resource_ID + Quantity + Units.

DFD Dictionary (concluded)

in the critical requirements and design phases, are detected both earlier and more reliably in such environments. Thus, productivity is consequently greater than under the historic rather free-form process.

The merits of such disciplined environments are greatly increased in the highly complex world of embedded software due to their intricate interfacing and timing requirements. The merits are still further enhanced in the case of large programming systems where a need for software subcontracting arises due to problem size; here the additional requirement of integrating products from several sources necessitates formal requirement and interfacing methods. All of the above complicating factors will be present in the Space Station software and will richly regard early formalization of the development process. It bears repetition that the role of software tools is to encourage the adherence to and effective use of an intelligently constructed set of standards and procedures. The tools should assist in the production, maintenance and testing of

all required software products, some of these being of the nature of documents, others being test data sets, code segments, etc.

2.5.2.1 Software Standards and Guidelines

It is stressed that "software tools" should properly be viewed as instruments to enforce and make convenient adherence to carefully formulated standards for software development. It was mentioned that Boeing has developed and adopted such standards for internal mandatory use for embedded software. Any standards which NASA may adopt should explicitly address two fundamental issues:

a. The life cycle definition employed

b. The software products – documents, code segments, test data sets, etc. which are to be produced in each life cycle phase; it should be explicitly stated which products are mandatory, optional, etc.

The SSE tool set adopted will then be expected to support the development of all software products identified by automating the use of these standards.

2.5.3 Requirements for the SSE

2.5.3.1 General SSE Philosophy

The Boeing view of the SSE is essentially one of a carefully crafted set of software development standards and associated products (code, documents, etc.), together with appropriate software tools permitting convenient computer-assisted adherence to those standards. It is further required, however, to offer a hardware environment for hosting such tools. This hardware environment is determined to a significant degree by the tool philosophy adopted. To illustrate, a reasonable policy is to buy commercial tools whenever suitable candidates exist, the alternative being to develop these in their entirety. The main advantages of this policy are that such tools are relatively inexpensive, error-free (due to larger using communities) and yield extensive capability in a relatively short time period. There are disadvantages to this approach in that the tools are often specific to particular hosts and are rarely integrated with other desirable software. In order to overcome these, a solution can be devised consisting of a distributed network of processors communicating via an appropriate Local Area Network (LAN) with integration addressed through the medium of a common Data Base Management System (DBMS) and tailored tool interfaces. Several popular larger proces-

sors should be employed for language processing, configuration management, etc., while single user work stations should be used to off-load the mainframes for smaller project oriented tasks.

It will, in the above conceptual architecture, be necessary to develop an operating system "kernel environment" to communicate with user and local processor operating systems, as well as to manage tool execution and DBMS activity.

The conjunction of a distributed network of popular processors (for which a rich commercial base of tools are available), the availability of suitable commercial tools to aid in the production of standard specified software products, together with common data management and user interface offers many outstanding advantages to the software development community and are as follows:

- Extensive and inexpensive capability in short time periods.
- Good system response through the addition of more processors.
- Support of software standards and associated products by an appropriate and convenient development environment.
- Tool integration.
- User-friendly standard interface.

2.5.3.2 System Definition

The remainder of this section is devoted to a description of the requirements for the SSE. As described earlier, Boeing views the SSE as an environment enabling convenient adherence to a carefully formulated set of standards.

2.5.3.2.1 General Description

The SSE system consists of:

- a. The software environment and tools required to automate and support the NASA standards, procedures, and guidelines.
- b. The hardware required to implement and support the software environment and tools.

2.5.3.2.1.1 Software System Equipment

Most tools have their own user interface and data base management system and schematics and do not communicate with each other; they are meant to do a single task and then exit. The SSE shall support the integrated set of software tools that are required for the total life-cycle support of embedded software. The environment shall provide:

- a. A flexible architecture that can easily integrate evolving technology and new tools as they become available.
- b. A uniform user interface for all software tools.
- c. Access control to all software tools and data.
- d. Execution control of all software tools.
- e. A uniform data base interface for all software tools
- f. A standard, data-structure representation of the user's project that can be created and used by tools in the concept definition life-cycle phase, passed on, developed further, used, and tested by tools in succeeding phases.
- g. User access via distributed workstations. Workstations shall be sup-

ported by host machines only as required to supplement the computational limitations of available workstations.

- h. The capability of communication between users of the system.
- i. The capability for compliance with the Ada Programming Software Environment (APSE) as described in document "Requirements for Ada Programming Support Environment".
- j. Ada language support in compliance with MIL-STD1850 and NASA Mandate.

2.5.3.2.1.2 Software Tools

Life-cycle support for embedded software requires the accomplishment of many tasks. These tasks are divided into three main areas that shall be supported by SSE software tools. These tasks are as follows:

- a. Management tasks.
- b. Engineering tasks – include all tasks required to cover the entire life cycle for the development of embedded software.
- c. General user support tasks – include all tasks of general use to both management and engineering tasks as well as office and administrative tasks.

2.5.3.2.1.3 Management Tasks

SSE shall provide software to aid managers in the following tasks:

- a. Planning
- b. Organizational interfaces

- c. Technical control
- d. Progress monitoring
- e. Software configuration control
- f. Procurement
- g. Cost management
- h. Software quality assurance

2.5.3.2.1.4 Engineering Tasks

In addition to the categories of engineering support tools specified below, SSE shall have a software tool for maintaining traceability of all project software requirements for the entire software life cycle. SSE shall have tools to support:

- a. Concept definition
- b. System design and requirements allocation
- c. Software implementation requirement development
- d. Basic design
- e. Detailed design
- f. Code and module test
- g. Software functional test
- h. Software formal test
- i. Operations and maintenance

Additionally, engineering tools shall be provided to aid in the development of proposals.

2.5.3.2.1.5 General Tasks

Software tools shall be provided to support those tasks that are of a general nature. These tasks are:

- a. Documentation support
- b. Text and graphics editor
- c. Data base management
- d. Configuration management
- e. Presentation materials generation
- f. Spreadsheet
- g. Electronic mail
- h. Report generation

2.5.3.2.1.6 Hardware Configuration

The hardware configuration shall:

- a. Support the execution of the environment and tools described in this document.
- b. Support both distributed execution of tools and distributed file and data base systems. This distributed capability shall be transparent to the user.
- c. Support communications with external systems.
- d. Support interactive user-computer communications via a microcomputer-based workstation with bit-mapped graphics display capable of displaying at least 80 columns by 24 lines of text.
- e. Support multiple workstations accessing a common set of output devices.
- f. Allow applications dealing with graphics data to access a color output device.
- g. Support real-time environment simulation and target computer testing.

2.5.3.2.2 Mission

The mission design goals of the SSE system are:

- a. To increase the overall productivity of personnel involved in the development of embedded software.
- b. To increase the overall quality of the software produced for embedded software projects.

2.5.3.2.3 System Identification

2.5.3.2.3.1 SSE System Diagram

The context of SSE within its external environment shall:

- a. Communicate with customer, prime contractor, or project personnel to:
 - (1) Accept external documentation
 - (2) Interact with status and control information
 - (3) Electronically deliver embedded software and associated documentation.
- b. Interact with project software management personnel to aid in project management.
- c. Interact with project software engineering personnel to develop the project software.
- d. Interact with project test engineering personnel to test the project software.
- e. Communicate with subcontractor.
- f. Communicate with external systems for transfer of information and data.

- g. Communicate with the target computer for downloading executable software, data, test control, and for receiving test responses.

2.5.3.2.3.2 Functional Areas

The SSE system consists of the following nine functional areas that shall support integration of tools and management, engineering, and general support tasks.

- a. Management (MGMT).
- b. Requirement Definition (REQ-DEF).
- c. Design (DESIGN).
- d. Construction (CONST).
- e. General User Support (GUS).
- f. Common Operational Software Tool Environment (COSTE).
- g. Test Preparation (TP).
- h. Test Conduction (TC).
- i. Post test Evaluation (PE).

2.5.3.2.4 Interface Definition

Interfaces to the SSE system are described in the following subsets:

Customer, Prime Contractor, or Project Personnel Interfaces

The external documentation, status and control, and the released software and documentation interfaces between customer, prime contractor, or project personnel and the SSE are defined in the interface standards. SSE shall support the electronic networks and standard protocols for these interfaces.

2.5.3.2.4.1 Man-Machine Interface

A uniform SSE Man-Machine Interface (MMI) shall encompass user interfaces to the following SSE users:

- a. Project software management personnel.
- b. Project software development engineers.
- c. Project software test engineers.

The SSE video display screen shall be divided into the following areas:

- d. Command-menu display area at the bottom portion of the screen.
- e. Message display area above the command-menu area.
- f. Tool display area in the remaining screen area.

These display areas shall be alterable by the user or an executing tool. The control language shall provide for:

- g. True defaults (e.g., parameters requiring absolutely no user action to accept).
- h. A command history log.
- i. Direct command entry.
- j. Menu-driven command selections.
- k. Development and execution of macros (e.g., user-defined names for a series of commands).
- l. Function key input.

2.5.3.2.4.2 External Systems Communications

SSE shall support the electronic networks and standard protocols for the following organizational interfaces:

- a. Technical staff.
- b. Systems engineering.
- c. Configuration management.
- d. Quality assurance.
- e. Program planning and control.
- f. Hardware design organization.
- g. System test.
- h. Security.
- i. Logistics engineering.
- j. Manufacturing.
- k. Contracts.
- l. Data management.
- m. Material.
- n. Finance.
- o. Software functional executive.
- c. Design (DESIGN).
- d. Construction (CONST).
- e. General User Support (GUS).
- f. Common Operational Software Tool Environment (COSTE).
- g. Test Preparation (TP).
- h. Test Conduction (TC).
- i. Post test Evaluation (PE).

2.5.3.2.5.1 Management

The SSE management functional area consists of the following SSE management subfunctional areas:

- a. Planning. This area will support the managers in planning software projects and life-cycle phases.
- b. Status. This area will support managers in collecting status information and making status reports.
- c. Control. This area will support managers in controlling the project or life-cycle phase while the software end items are being developed.
- d. Review. This area will support managers in reviewing completed end items and completing life-cycle phases.

The following sections will show how the SSE subfunctional areas will support the management tasks:

2.5.3.2.5.2 Planning

2.5.3.2.5 Functional Area Characteristics

The SSE system consists of the software environment and support tools to automate and support NASA standards, procedures and guidelines and the hardware to implement the environment and tools.

The SSE software functional characteristics are described under the following functional areas:

- a. Management (MGMT).
- b. Requirements Definition (REQ_DEF).
- a. Planning (SSE management subfunctional area) shall provide support for software managers to do the

following management planning tasks:

- (1) Prepare the software manager's input to the proposal.
 - (2) Prepare a preliminary software development plan.
 - (3) Decompose the software program plan into work packages.
 - (4) Revise the work packages throughout the software development.
- b. Planning shall provide support for software managers to make an organizational structure.
 - c. Planning shall provide support for software managers to set project standards.
 - d. Planning shall provide support for software managers to:
 - (1) Make Progress Tracking Schedules and incorporate the schedules into the work packages.
 - (2) Revise Progress Tracking Schedules according to changes.
 - e. Planning shall provide support for software managers to:
 - (1) Do procurement planning.
 - (2) Make subcontractor selection.
 - f. Planning shall provide support for software managers to:
 - (1) Do cost estimation.
 - (2) Do risk analysis.
 - (3) Do budget allocation

- g. Planning shall provide support for software quality assurance managers to:

- (1) Participate in project planning.
- (2) Develop a Software Quality Assurance Plan.

2.5.3.2.5.3 Status

- a. Status shall provide support for software managers to:

- (1) Make technical performance measurements of computer resources.
- (2) Do requirements traceability.

- b. Status shall provide support for software managers to:

- (1) Collect status information from tasks.
- (2) Update Progress Tracking Schedules.
- (3) Compare progress status with plans and determine variances.

- c. Status shall provide support for software managers to execute the subcontract.

- d. Status shall provide support for software managers to:

- (1) Do cost collection.
- (2) Do cost tracking.

- e. Status shall provide support for software quality assurance managers to monitor all software development activities.

2.5.3.2.5.4 Control

- a. Control shall provide support for software managers to coordinate with all organizations concerning software development activities.
- b. Control shall provide support for software managers to make controlled engineering releases.
- c. Control shall provide support for software managers to:
 - (1) Review variances and impact of changes.
 - (2) Coordinate with others.
 - (3) Make changes and send to Planning.
- d. Control shall provide support for software managers to execute the contract.
- e. Control shall provide support for software managers to:
 - (1) Do cost collection
 - (2) Do cost tracking
- f. Control shall provide support for software quality assurance to monitor all software development activities.

2.5.3.2.5.5 Requirements Definition

Software tools shall be provided to support the definition, documentation, and analysis of software requirements. Products of subsequent life-cycle phases must be traceable to the requirements.

2.5.3.2.5.6 Requirements Analysis

A combination of graphical and textual capabilities shall be provided to enable software engineers to develop and document

software requirements. Requirements shall be stored and available for subsequent processing by requirements analysis tools.

Top-down development of requirements shall be supported. A user shall be allowed to start at any level of requirements and add upper or lower level nodes. Support shall be provided to allow a user to insert nodes, delete nodes, move nodes, or change nodes. Nodes shall be uniquely identifiable.

Support shall be provided to enable a user to input, preserve, recall, and analyze data flows and control flows between nodes. The requirements definition capability shall support the adaptation of different software development methodologies. Development of detailed requirements, such as equations, algorithms, scaling information, display formats, and timing data, shall be supported. The product of requirements definition shall be transferable to the documentation support system and easily incorporated into project documents. The product of requirements definition shall be transferable to software design tools for subsequent analysis and transformation.

2.5.3.2.5.7 Simulation

Simulation modeling tools shall be provided to support modeling of computer system components, to conduct preliminary performance evaluations, and to analyze computer sizing and timing estimates. A computer system simulation modeling and analysis support system shall be provided for construction of computer system models for simulation analysis of hardware and software designs. This tool shall support the total simulation process which consists of concept development, design, implementation, execution, and analysis of simulation results.

2.5.3.2.5.8 Requirements Traceability

Identification, classification, and cross-indexing of requirements shall be supported. Requirements shall be traceable across all documents. The requirements traceability capability shall support impact analysis, in determining what software components and documents are affected by proposed requirement changes.

2.5.3.2.5.9 Interface Requirements Definition

Support shall be provided to enable the development of interface requirements.

2.5.3.2.5.10 Allocation

Support shall be provided for allocating requirements to hardware and/or software components.

2.5.3.2.5.11 Prototyping

Two types of prototyping shall be supported - functional and man-machine interface.

2.5.3.2.5.12 Design

Design tasks consist of design analysis, interface definition and data base design. Support shall be provided to enable close coordination and simultaneous development of these tasks.

2.5.3.2.5.13 Design Analysis

A combination of graphical and textual capability shall be provided to enable a software engineer to develop and document software design. Consistency checking between requirements definition and design shall be supported. The capability shall be provided to support different software development methodologies. Top-down design development shall be supported. A user shall be allowed to start at any level

of design and add upper and lower level nodes. Support shall be provided to allow a user to insert nodes, delete nodes, move nodes, or change nodes. Nodes shall be uniquely identifiable.

The product design information shall be available for subsequent analysis.

2.5.3.2.5.14 Interface Design Definition

Software tools shall be provided to support the design of software interfaces.

2.5.3.2.5.15 Data Base Design

A tool shall be provided to support data base design, and data base analysis. A capability shall be provided to support coordination between data base design and software design.

2.5.3.2.5.16 Construction

Tools shall be provided to support code construction through module test. Additional module test support is provided by testing functions for downloading and testing on target computers.

2.5.3.2.5.17 Editors

Programming language context editing shall be supported.

2.5.3.2.5.18 Code Generation

Tools shall be provided to enable the generation of executable code.

2.5.3.2.5.19 Compilers/Assemblers

The SSE will provide the Ada compiler and environment.

2.5.3.2.5.20 Integration

Integration is the process of collecting software modules in object code form and

building executable code. Software tools shall be provided to support this activity.

2.5.3.2.5.21 Analysis

Tools shall be provided to support static and dynamic software analysis.

2.5.3.2.5.22 Instruction-Level Simulation

Tools shall be provided to support instructional level simulation of the various target computer architectures to be used in the SSE.

2.5.3.2.5.23 Reusable Software Library

A Reusable Software Library (RSL) shall be provided for storage of reusable project application software, software tools, and procedures. Software tools and procedures shall be provided to support maintenance and control of reusable software.

2.5.3.2.5.24 Document Support

The Document Support System shall support the generation and maintenance of all project documents. Maintenance shall include adding, deleting, and modifying text and graphics contained in the documents. This tool shall provide support for:

- a. Electronic reading, commenting (red line), and approving all documents.
- b. Author review of red-line comments for possible inclusion into the document.
- c. Automatic generation of:
 - (1) Change bars
 - (2) Revision level of each page.
 - (3) A page classification level based on the classification of its paragraphs.
 - (4) Active record sheet.

- d. Production of revised pages (SSE added) when user directs.

- e. Text editor for editing documentation.

- f. Graphics editor for editing graphics.

2.5.3.2.5.25 Presentation Graphics

A colored presentation-graphics capability shall be provided to support on-line preparation of text and graphical material.

The tool shall support preparation of bar charts, line charts, and pie charts and overlays.

The tool shall support formatting of the graphics for hardcopy devices.

The tool shall be capable of utilizing data from other text and graphics tools.

The presentation graphics shall include a spreadsheet tool with graphic capabilities.

2.5.3.2.5.26 Data Base Management

SSE shall provide a data base management capability. This capability shall:

- a. Manage relational data.
- b. Have an interactive query language.
- c. Have a report generation capability. This capability shall allow for textual reports, and graphic representation of data contained in the data base.
- d. Have a form management capability. This capability shall allow the user to define forms and then use those forms for entering data into the data base.
- e. Have a higher order language interface to the data base. This language

shall provide means so that SSE software can be developed to interface with the data base.

2.5.3.2.5.27 Software Configuration Management

Tools shall provide for the control, identification, and monitoring of the software configuration baseline. These tools shall provide both software configuration management for the system software and software configuration management for the project-developed deliverable software. The configuration management shall provide the following:

- a. Identification of configuration controlled items.
- b. Configuration change control.
- c. Computer program library support.
- d. Configuration status accounting.
- e. Release-coordination support.
- f. Query and report generation.

Model management tools shall be provided for the user to:

- (1) Extract a working model (copy) from the parent model held in configuration management.
- (2) Merge, add, subtract, or compare working models.
- (3) Replace a specified model held in configuration management with an approved updated model.

2.5.3.2.5.28 System Backup

The SSE shall provide the capability to backup the mass storage file system.

2.5.3.2.5.29 Gateway

The SSE shall provide communication to external systems via the gateway.

2.5.3.2.5.30 Security

In recognition of NASA/contractors security requirements concerning the proprietary nature of many embedded software systems at NASA, SSE will implement a multilevel security system as the technology becomes available.

2.5.3.2.5.31 Operating System

The Operating System (OS) shall provide:

- a. Resource management that shall:
 - (1) Manage SSE mass storage system.
 - (2) Manage memory and processors available to the system.
- b. Manage peripherals attached to the system.
- c. Software tool execution control that shall:
 - (1) Control the execution of both interactive jobs and background jobs.
 - (2) Utilize user priorities assigned for interaction, and background or batch jobs.
- d. Communications management that shall:
 - (1) Manage the communication between all elements of the system via the SSE network.
 - (2) Interconnect workstations, computers, and terminals.

- (3) Transfer information between similar and/or dissimilar computers within the same network.
 - (4) Transfer information between similar and/or dissimilar networks at a minimum of 10 MBps.
 - (5) Transfer data files between similar and/or dissimilar computers within the same network or across gateways with no conversion required by the sending or receiving application program. Any required conversion shall be accomplished by the network managers in each computer or by the gateway between networks.
 - (6) Support interactive communications between workstations, terminals and computers within the same network.
- e. Operating system security that shall:
- (1) Require authorized users to enter their unique user name and password to gain entry to their account on the system.
 - (2) Provide users of the SSE system to gain access to other accounts on the system if and only if the owners of the accounts have granted such privileges to those users.
 - (3) Require each file on the system be owned and controlled by a specific account on the system.
- f. Resource accounting tools that shall:
- Provide statistics on:
- (1) Provide statistics on: Sign-on frequency by user ID including date and time.
 - (2) Provide statistics on: Frequency of individual tool execution including time of day and duration.
 - (3) Provide statistics on: Memory used, CPU used, disk I/Os, disk storage and system response time and system internal performance.
- g. Relate resource use to individual phases of the software life cycle.
- #### 2.5.3.2.5.32 Environmental Services
- The environmental services shall provide:
- a. A common integrated data structure for each project that shall:
 - (1) Represent the user's project through the full software life cycle.
 - (2) Include:
 - a) Manual interpreted data (e.g., text and diagrams).
 - b) Software interpreted object sets which are defined in classes.
 - c) Work space for individual users and tools.
 - (3) Allow an entity to be stored in only one home place in the data base.
 - (4) A knowledge base for use by artificial intelligence tools (e.g., expert systems).
 - b. A uniform data base interface for all software tools.
 - c. A uniform user to software tools interface that shall:

- (1) Be standardized for COSTE and all software tools.
- (2) Utilize a control language that is easy for the novice to learn and use, as well as efficient for the experienced user.
- (3) Accept input from interactive devices (e.g., keyboard, mouse, or graphics tablet).
- (4) Be able to accommodate selected interactive technologies as they become available.

d. Online help facilities that shall:

- (1) Have online help facilities for all software tools and the environment.
- (2) Provide users with online help when requested before entering any command.
- (3) Provide access to an online catalog of available software tools.
- (4) Provide access to an overview of the SSE system and its components.

2.5.3.2.5.33 Test Preparation

The Test Preparation Function consists of tools to support test documentation and test environment generation.

2.5.3.2.5.34 Test Documentation Generation

These tools provide the capability to generate test plans, test descriptions, test procedures, and analyze these for test sequence correctness, completeness and provide traceability analysis. These tools consist of the following:

- a. The Test Plan Generator shall provide the user the capability to produce test plans and the module test

plan using the requirements, ICD's, IDD's, and user input.

- b. The Test Description Generator shall provide the user the capability to produce test descriptions using the requirements, ICD's, IDD's, test plan and user input.
- c. The Test Procedure Generator shall provide the user the capability to produce test procedures and using the requirements, ICD's, IDD's, test description and user input.
- d. The Pre-test Analysis tools shall provide the user the capability to analyze the test plans, descriptions, and procedures for completeness, test sequence correctness, and shall provide traceability analysis.

2.5.3.2.5.35 Test Environment Generation

These tools provide the capability to create test environment components and assemble them into a test environment. These tools consist of the following:

- a. The Test Scenario Generator shall provide the user the capability to produce mission data that is external to the operational software being tested but which is necessary for performing a simulated mission.
- b. The Test Script Generator shall provide the user the capability to produce detailed instructions that automate the control of the test using the test procedures and user input.
- c. The Test Support Data Generator shall provide the user the capability to produce data needed to support

operation of the simulation environment and test scenario.

- d. The Simulation Environment Generator shall provide the user with modelbuilding tools to produce simulation models, and tools for assembling models, stubs and drivers to produce an integrated simulation environment. The simulation models will be stored and retrieved from the Reusable Software Library.
- e. The Assemble Test Environment software shall provide the user the capability to produce integrated test environments assembled from test scenarios, test scripts, test support data and the simulator environments previously created.

2.5.3.2.5.36 Test Conduction

The Test Conduction Function consists of software that supports execution of the test in both the host and target systems. This function consists of the following software:

- a. The Control Test Execution software shall provide the overall control of the test's execution. It shall be capable of executing a test defined by a previously created test environment or accept test instructions from the user's console. The Control Test Execution software shall also provide a test log of test activities.
- b. The Test Downloader software shall download the testenvironment, target code and test script.
- c. The Test Instrumentation Control software shall accept commands received from the Control Test Execution software, process the command and send the resultant command to the test instrumentation.
- d. The Test Instrumentation Monitor software shall monitor the test instrumentation to receive status and test data from the test instrumentation. It shall provide status information to the Control Test Execution software and the test data to the Test Data Collection software.
- e. The Environmental Simulator Control software shall accept commands received from the Control Test Execution software, process the command and send the resultant command to the environmental simulator.
- f. The Environmental Simulator Monitor software shall monitor the environmental simulator to receive status, and test data from the environmental simulator. It shall provide status information to the Control Test Execution software and the test data to the Test Data Collection software.
- g. The Target System Control software shall accept commands received from the Control Test Execution software, process the command and send the resultant command (target system stimulus) to the target computer instrumentation.
- h. The Target System Monitor software shall monitor the target computer to receive status, and test data (target system responses) from the target system instrumentation. It shall pro-

vide status information to the Control Test Execution software and the test data to the Test Data Collection software.

- i. The Test Data Collection software shall receive test data from the Test Instrumentation Monitor software, Environmental Simulator Monitor software, and the Target System Monitor software. It shall time tag the test data and store it for later use by the Post Test Evaluation Function. It shall also provide, under Control Test Execution software command, selected data items to the Output Test Data software.
- j. The Output Test Data software shall perform real-time reduction, and analysis, and output selected test data under Control Test Execution software command.
- k. Instructional level simulation of the target systems shall be provided for under Control Test Execution software command.
- l. Symbolic debuggers for the languages shall be provided for under control Test Execution software command.
- m. Source code debuggers for the languages shall be provided for under Control Test Execution software command.

2.5.3.2.5.37 Post Test Evaluation

The Post Test Evaluation Function consists of tools required to reduce, analyze, and evaluate the raw data collected from the

test. This function consists of the following tools:

- a. The Data Reduction tools shall provide the user with the capability to reduce raw data collected from the test.
- b. The Data Analysis tools shall provide the capability to analyze the reduced test data based upon user specified criteria.
- c. The Data Evaluation tools shall provide the user with the capability to evaluate the test data and verify that the test meets the test requirements.
- d. The Test Report software shall provide the user the capability to produce module and performance test reports using the data evaluation results, test documentation, requirements, Interface Control Document (ICD)'s, Interface Data Document (IDD)'s, and user input.

2.5.3.2.5.38 Workstation

Workstations shall be available in two generic configurations consisting of a standard and a high performance configuration respectively.

A standard workstation shall consist of:

- a. An ergonomic work environment.
- b. A microcomputer with access to IOM bytes of private disk storage.
- c. One bit-mapped graphics CRT that shall have:
 - 1. A color display.

2. At least 12-in-diagonal screen size.
 3. At least 2300 displayable pixels per square in.
 4. The ability to display at least 80 columns by 24 rows of text.
- d. A keyboard.
 - e. A hand pointing device (e.g., mouse, graphics tablet)
 - f. Software support for both a mouse and a graphics tablet.

A high-performance workstation shall consist of the components of a standard workstation with the following substitutions:

- g. The microcomputer shall have at least 32-bit architecture with access to 10M bytes of private disk storage.
- h. The display shall be a text and graphics video display.
 1. At least a 12-in-diagonal screen.
 2. At least 4600 displayable pixels per square in.
 3. The ability to display at least 80 columns by 24 rows of text.

2.5.3.2.5.39 Host Computer

The host computer shall:

- a. Support intelligent workstations.
- b. Be capable of supporting a distributed O/S.
- c. Support specified performance requirements.

- d. Provide at least the capability of a supermini.
- e. Be the VAX and IBM computers.
- f. Provide the capability to complete complex processing tasks on a timely basis, as well as function as a file server, mail server, and internet gateway.

2.5.3.2.5.40 Output Peripherals

Output peripherals shall support:

- a. Remote locations from workstations and/or hosts.
- b. Draft-quality and high-quality text hardcopy.
- c. High-resolution color graphics hardcopy.
- d. Intermixed high-quality text and graphics hardcopy.

2.5.3.2.5.41 Test Hardware

The test hardware shall support:

- a. A range of target systems from microprocessor to mainframe.
- b. Real-time simulation of target system environment.
- c. Target system instrumentation to monitor and control the target system.
- d. Test instrumentation to monitor target system hardware performance.

- e. A test engineering workstation that includes a workstation specified in previous workstation section.

2.5.3.2.5.42 Hardware Operational Modes

The host and workstation environment shall be configured for system performance and response.

2.5.3.2.5.43 Machine Concept

An object-oriented DOS shall be used to provide the machine system for the SSE System. An object contains the data structures, as well as instructions for operation. The boundaries between different systems shall be made transparent to the users.

2.5.3.2.5.44 Distributed Processing

Central processing unit resources shall be shared using distributed processing.

Load balancing shall determine which machine will run a process.

2.5.3.2.5.45 Distributed Data Bases and Files

The software data base and file system shall be designed for meeting the system response requirements.

2.5.3.2.5.46 Project Utilization

Large projects using SSE shall be able to have a dedicated version of the SSE system resident at the project site. Smaller projects may use the SSE which is resident in the Software Development Laboratory (SDL). The SDL shall be able to support multiple project users.

2.5.3.2.5.47 Network Characteristics

The system shall make use of networking. A Local Area Network (LAN) shall be used to interconnect the various equip-

ment in the system. Wide area networks, and an internetwork shall be used to expand system capabilities as required. System networks shall be capable of interconnects through gateways to other networks. Networking shall be transparent to the user. High-speed networking of various bandwidths shall be employed in the system. The standard seven-layered model as determined by the International Standards Organization shall be used.

2.5.3.3 Characteristics

2.5.3.3.1 Performance

For the purposes of evaluating system performance, there shall be two types of commands, process and interactive. Process commands initiate the execution of a process (i.e., task) and may or may not subsequently involve interactive commands. Interactive commands establish a user-computer dialogue once a process is started.

A process command shall be responded to or acknowledged within 0.5 seconds of input. For an inherently long process, a facility shall be provided that allows users to execute the process in a background mode, even after it has started executing in a foreground mode. Also, system statistics shall be provided to users so that they may gauge the progress of the process. Inherently long is defined as a process requiring more than 15 seconds to complete when only one user is on the system.

For interactive commands, the system shall respond to or acknowledge the command within 0.5 seconds. Interactive commands that do not activate a process shall be responded to within 0.5 seconds. Acknowledgment is that the system displays, or in some way indicates, that a command was entered. System response is that the system indicates that the command was

accepted or rejected and prompts the user for additional input.

2.5.3.3.2 Physical Characteristics

A well designed work environment shall be an integral part of the total software system environment.

Workstations shall be close and easily available to system users. Printers, disk drives and other peripheral equipment likewise shall be easily accessible and not adversely disturb the user's work environment.

2.5.3.3.3 Reliability

A reliability SSE system shall be achieved by following the NASA software life cycle practices. Additionally, there shall be tools provided for assisting in predicting, identifying, recording, reporting, and tracking software and hardware errors and associated activities.

2.5.3.3.4 Maintainability

Software and hardware developed by SSE personnel shall be maintained by NASA personnel. Licensed software and purchased hardware shall be an inherent part of the SSE configuration definition. Purchased software and hardware shall be maintained by the companies from which the software and hardware were purchased unless otherwise negotiated.

2.5.3.3.5 Availability

The system shall be available 99 percent of two working shifts during twenty-four hour periods when the main power is on. In this case, availability shall be defined as access to all or any part of the system that allows work to be performed.

2.5.3.4 Methodologies for Software Development

2.5.3.4.1 Software Development Plan

The Software Development Plan (SDP) describes the comprehensive plan for the Software End Item development. The SDP includes a description of the development organization, a description of the development approach, milestones and schedules, and resource allocation. Details can be found in DR-16.

2.5.3.4.2 Software Test and Integration Plan

The Software Test and Integration Plan is an integral portion of the SDP and is the overall plan for performance evaluation testing of Software End Items. Performance evaluation tests are those tests that are conducted to verify that a Software End Item (computer program) satisfies the requirements of the Software Requirements Specification (SRS) and Software Implementation Requirements Document (SIRD). The plan describes facilities and resources to be used; personnel requirements; test conduct, test control and test reporting methods; and the tests to be conducted.

2.5.3.4.2.1 Requirements

The Software Test and Integration Plan shall include both functional and formal tests. The following sections specify the contents of the plan. The plan is not included. It will be expected to be a C/D product.

a. Introduction

This section shall state the purpose and scope of this test plan, and shall identify the Software End Item to which it applies.

b. Applicable Documents

This section shall identify all documentation that was used as a basis for the test plan, or that is required to support the tests specified. Documents defining the Software End Item configuration to which the test plan applies shall be identified. For existing documents, the title, version, date of issue, and publisher shall be included in each document. Unreleased Boeing documents, such as the software part drawing, should be so indicated.

c. Test Item Description

This section shall contain a brief functional description of the Software End Item and its external interfaces.

d. Test Levels

This section shall describe briefly the levels of tests to be applied to the Software End Item. Use a separate paragraph for each level (module, computer program integration, functional, and formal). State the purpose, responsibility and general methods to be used at each level. Describe the relationship among test levels and the differences between functional and formal tests. Make the descriptions specific to the software under test; if there are conditions that make it impossible to verify all specification requirements at the formal software test level, so state.

e. Participating Organizations

This section shall list each participating organization and its responsibilities and tasks. This shall include: (1) the test organization, and (2) a listing of test person-

nel requirements by agency or organization.

Organizations responsible for test activities including overall test direction, test conduct, test operation, data analysis, test reporting, test witness or verification, test configuration controls, and hardware and software maintenance during test shall be identified.

Test Schedule and Location

This section shall identify the schedule and location of the testing. The schedule shall be established relative to milestones in the overall software development schedule. The schedule shall indicate time-phasing of significant actions related to preparation and conduct of the test, for example: SRS and SIRD availability; completion and approval of test plan, test descriptions, test procedures and test report; Test Readiness Reviews; functional and formal testing periods.

Test Support Requirements

This section shall include a description of technical support for the test program, describe all facilities and equipment required to support the test, describe all required test support software, and describe all test instrumentation requirements.

Security Requirements

This section shall identify all proprietary equipment, software, procedures, and documentation required for the test. When proprietary data is involved, procedures for safeguarding this data during the entire process shall be stated here.

Data Collection, Reduction, and Analysis

This section shall describe general procedures for data handling and analysis of test results. The procedures shall indicate the following: (1) the procedures for col-

lecting, labeling, storing, and distributing data; (2) analysis methods; (3) requirements for data processing equipment (including approximate computer time required) and any Software End Items required for data collection and analysis; and (4) organization responsibilities for the above tasks.

Test Documentation

This section shall describe the requirements for preparing tests description and test procedures for functional and formal tests and for preparing test reports.

Test Control Procedures

This section shall specify requirements for test control, including (1) Test Readiness Review conduct; (2) configuration control of test hardware and software; (3) test procedure handwritten control; (4) test witness or verification; (5) maintenance and test logs; (6) test progress control and reporting; (7) use of a company formal testing and production record system; (8) reporting of and resolution of discrepancies; and (9) documenting and controlling special tests.

2.5.3.5 Advanced Technologies

This section discusses areas of technology that appear to be beyond the current capabilities of industry and research. However, the potential of each technology is such that the SSE should track its development for future inclusion of that tool. The areas identified and described on the following pages are:

- a. Rapid Prototyping
- b. Very High Order Languages (VHOLs)
- c. Cost Estimation
- d. Reusable Software

e. Artificial Intelligence

2.5.3.5.1 Rapid Prototyping

One major problem in building acceptable software systems is the current lack of continuing communication between customers and developers, which means that only when the programmer has produced something to look at can the customer decide whether it is what was asked for. If the customer's examination is delayed until the software system is supposedly ready for delivery, then much time may be wasted if the system is unsatisfactory. The user may reject software because a program does not match its original specifications. Frequently, however, a finished program may be rejected because the original specifications were not a good description of what the customer wanted.

Rapid prototyping is one approach being explored to get a good idea of how a program should be designed before too much effort has been expended in coding. A rapid prototype is an executable model of the intended system that shows in general how the final system will look to the customer and how it will function. The prototype may not have all the functionality of the final system, but it will contain enough of the customer's initial specifications for the system to indicate whether major changes should be made. Such a prototype can also give the developer insight into how the final system should be implemented. It can be quickly changed until both the developer and the customer agree on its appearance, thus giving both parties a better idea of how the final system should look rather than if they were working from paper specifications. Having fulfilled its purpose, the prototype should generally be thrown away rather than being used as a base in developing the target system.

2.5.3.5.2 Very High Order Languages (VHOLs)

Rapid prototyping will most likely utilize very high order languages to accomplish an increase in productivity. A VHOL will incorporate another layer of leverage in elevating the use of computers toward a human level. The VHOL will increase computer capabilities over a high order language (HOL) just as the HOL has increased capabilities over Assembly languages in the past. With each step, the leverage increases by an order of magnitude to optimize:

- reliability
- productivity
- cost savings

The above factors present sufficient readiness for pursuing the applicability of VHOLs for the Space Station Project. Such a VHOL will enable non-programmers to develop software for specialized systems in a reliable and timely manner. It

will decrease the number of software engineers needed for developing a program which in turn simplifies and minimizes the interfaces.

Having realized the enormous problems involved with developing large, complex software programs, Boeing has already begun research and development efforts to design and build a VHOL called an Application Generator. With the time constraints associated with the Space Station, such a VHOL may ultimately prove to be a deciding factor of which functions will appear at what level of implementation of the Space Station.

Since the User interface language is the most accessed language in any computing system, heavy emphasis should be placed on the capabilities incorporated into it. To maximize the productivity of the users of the computing system, state of the art human factors engineering should be a vital factor in the design.

3.0 CUSTOMER ACCOMMODATIONS

3.1 Purpose

The purpose of this section is to describe the accommodations provided by WP-01 in the Space Station United States Laboratory (USL) module for its users. The term 'customer' is used in this context to describe any agency which expresses an interest in the use of the USL microgravity facility. The customers range from individuals and small corporations to government agencies and large corporations both within the USA and outside.

3.2 Approach

The Station Accommodations Test Sets (SATS) are the basis for assessing the capability of the USL in meeting the predicted needs of the users. Where additional technical data is available but judged to be beyond the scope of this section, references are provided. It is assumed throughout this section that the science accommodations include both materials processing and life sciences and that, generally, the same requirements pertain to both.

3.3 The United States Laboratory Module

The USL is a national resource providing a working environment having very low gravitational effects referenced to earth surface levels. It has limited resources of volume, dimension, electrical power, thermal control, data management, experimental equipment and life support systems, etc.

3.4 Procedures for Customer Access

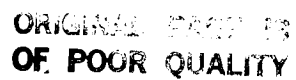
Figure 3.4-1 is a procedure flow chart illustrating the individual steps necessary to complete a customer/Space Station negotiation and the successful completion of an experiment/process cycle.

3.5 Space Station Initial Operating Capability

Figures 3.5-1 and 3.5-2 illustrate the Initial Operating Capability (IOC) of the Space Station. It shows a twin keel arrangement with one habitat module, one laboratory module, one logistics module and two international modules installed close to the Station center of mass. The microgravity level in the vicinity of the USL is shown in Figure 3.5-3. Electrical power is derived from photovoltaic arrays and solar concentrators delivered to the modules as high voltage, high frequency energy, reconverted and distributed to each equipment rack interface panel. Thermal rejection is provided by active tower radiators via interface heat exchangers on the module which are connected to the USL water cooling loops which service the racks.

3.6 Module Growth

USL growth will be provided through the use of the basic resources such as power, thermal rejection, data transmission etc. up to the physical limits of USL capacity and resources availability. Thereafter, growth will be by the addition of more modules. For example, during late IOC a dedicated module for a four-meter diameter centrifuge and/or other life sciences installation may be added.



Sheet 61

TRACKING AND DATA RELAY SATELLITE (TDRS) ANTENNA

TETHER

ZENITH PAYLOAD DECK

SATELLITE SERVICING FACILITY AND HANGAR

ESA

JEM LOGISTICS MODULE

JEM

U.S. HABITATION MODULE

POWER RADIATOR

THERMAL RADIATOR

OMV ACCOMMODATIONS

LOGISTICS MODULE

TUNNEL

LABORATORY LE

PHOTOVOLTAIC ARRAY

SOLAR DYNAMIC COLLECTOR

ALPHA JOINT

AIRLOCK

Sheet 62

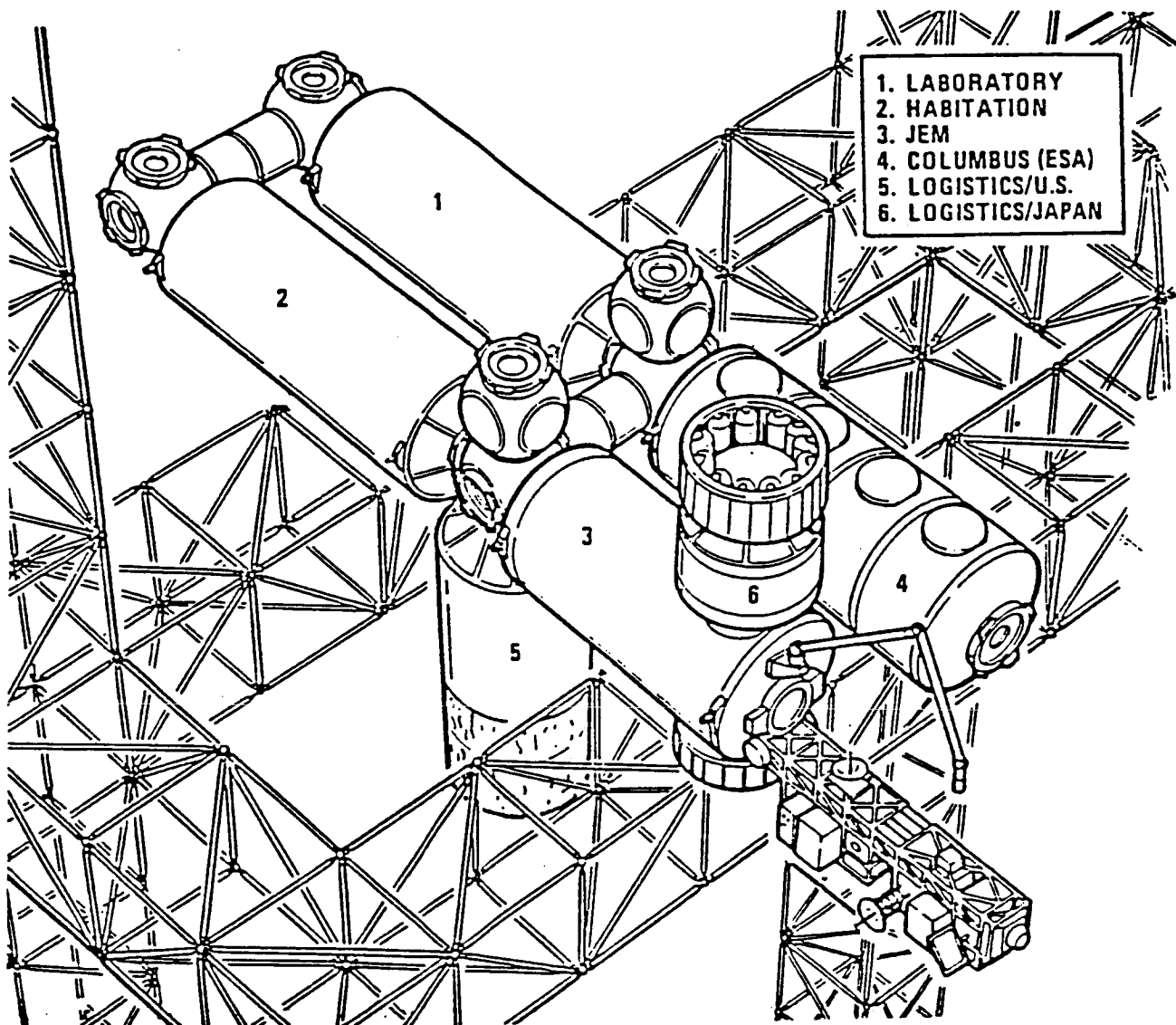


FIGURE 3.5-2 SPACE STATION INITIAL OPERATING CONFIGURATION (MODULE ASSEMBLY)

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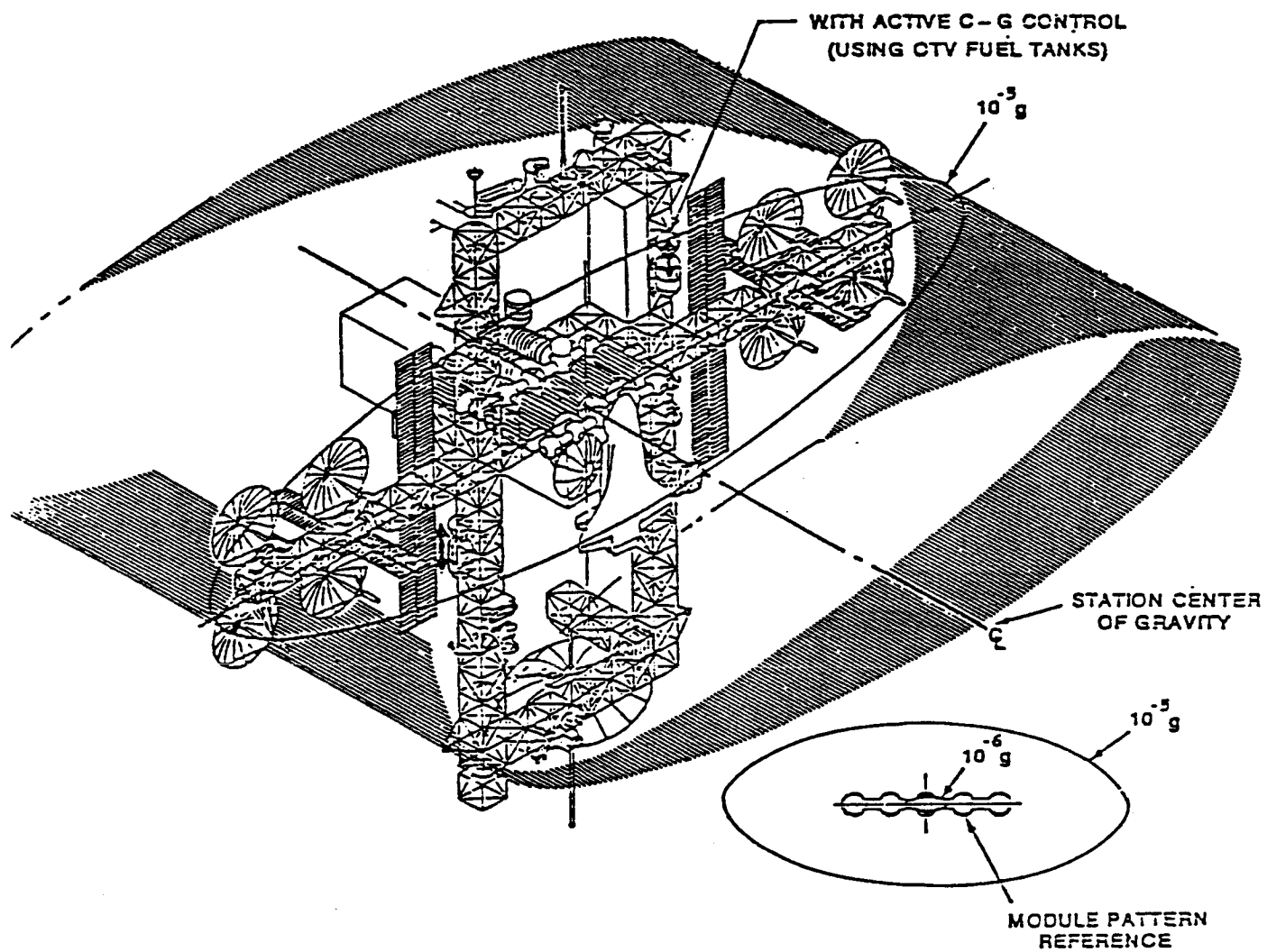


FIGURE 3.5-3 MICROGRAVITY ENVIRONMENT AROUND THE SPACE STATION

3.7 U.S. Laboratory Module

3.7.1 Scope of Research and Development Accommodated

The USL is intended to accommodate as wide a range of R & D as is possible within the constraints of STS launch, logistics and on-orbit safety. The types of R & D activities accommodated at the Space Station are shown in Figure 3.7.1-1. This model of the innovation process classifies the purpose of a particular R & D project and shows the role of that project within a R & D program. Note that within each phase of R & D, there are parallel activities under the categories of research, technology development and commercial development. The U.S. Laboratory Module can, if required by the industrial customer, accommodate each step of R & D activity in parallel with commercial development activities on the ground. This model provides a better picture of knowledge and product generation than simply classifying R & D as either basic (divergent) or applied (convergent) research, and promotes understanding among customers as to the precise needs of any one customer for the facilities provided at the Space Station.

The diversity of R & D purposes among USL customers requires careful use of terms to describe a customer's activities and property. 'Payload' is the general term for the customer's property on-orbit. The payload can be further described according to its purpose, or in such equivalent terms as experiment, lab bench-scale prototype, testbed, etc. 'Facility', refers to a provided apparatus or volume in the USL where payload processes are performed.

3.7.1.1 Classes of Payloads

There are at present two types of payloads and are categorized as follows: 1) the STS-middeck-type of payload, which is essentially self-contained, small, requires little energy and manipulation by the crew, and is therefore rather limited in scope; 2) the Spacelab-type payload, which approaches the experimental flexibility of laboratories on the ground but again has obvious resource limitations.

3.7.1.2 Payloads Accommodated

Payload classes accommodated by the USL will include those in paragraph 3.7.1.1, but only within a much broader range of possible payload accommodations (Table 3.7.1.2-I). A USL-class payload will include such additional accommodations as direct access to the core of the payload apparatus, either by the crew or robotics.

3.7.1.2.1 Life Sciences

Life sciences includes biology, biomedicine, exobiology and biospherics. The remaining disciplines are under materials processing, including bioprocessing.

3.7.1.3 Station Accommodation Test Sets (SATS)

Station Accommodation Test Sets are specific R & D missions compiled by NASA from customer and other inputs. They are not intended to exclude disciplines or payloads. These SATS were selected to evaluate designs of space station elements in terms of the level of accommodation provided to a variety of payloads and disciplines. The full range of test sets is shown

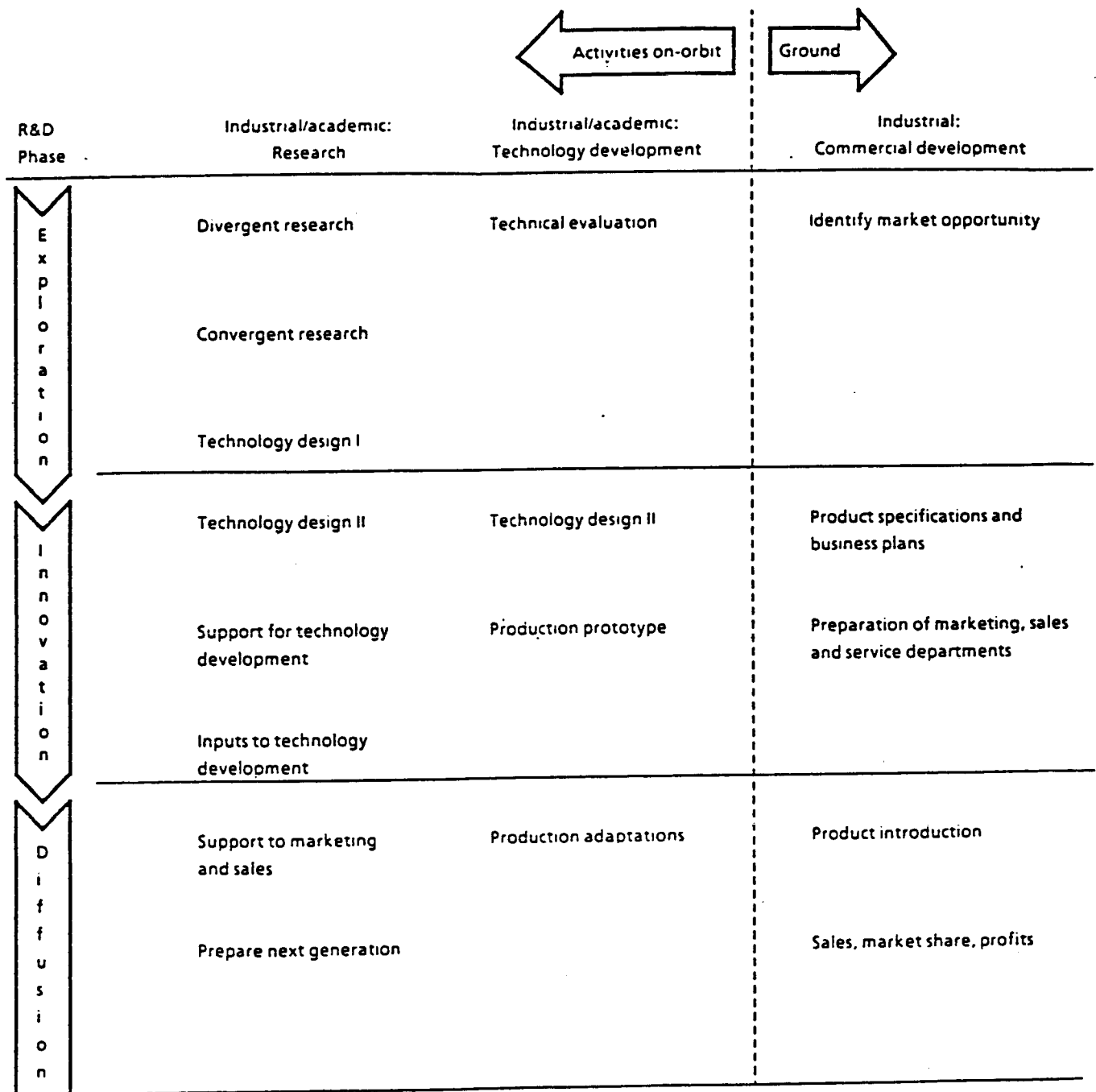


FIGURE 3.7.1-1 TYPES OF R&D ACTIVITY PERFORMED AT THE SPACE STATION

TABLE 3.7.1.2-I CLASS OF PAYLOAD ACCORDING TO PHYSICAL CHARACTERISTICS: VAPOR PHASE CRYSTAL GROWTH

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Payload characteristic	Accommodation range		
	Less	→	More
Volume	Stowed within one rack	Mounted in one or more racks	Mounted in two or more rack-equivalent volumes
Energy flow	Less than one kW	One to five kW	More than five kW
Materials flow	Small quantities	Supplied by customer in replaceable containers, waste returned same way	Managed by Space Station, centralized distribution and substantial logistics up/down
Data flow	Managed by customer within payload	Some interfaces with on-orbit subsystems, some use of on-orbit software for analysis	Extensive data points, data storage, processing, analysis, interfaces and downlink
Containment	Acceptable in cabin atmosphere, may require controlled air flow	Hard shell, two-fault tolerant containment throughout functional flow	Kept inside a three-fault tolerant container on-orbit, and used in small amounts
Manipulation	No direct access to core apparatus	Automation and robotics sufficient for all manipulations of core apparatus	Direct access by crew members to core apparatus
Spaceflight qualification	Most of hardware is spaceflight-qualified	About half of apparatus consists of spaceflight-qualified hardware	Little or no hardware previously spaceflight-qualified
Need for lab support equipment	Self-contained	Some use of typical laboratory instruments and tools	Numerous associated processes which require on-orbit support equipment

in Table 3.7.1.3-I, without descriptions of the codes assigned to specific missions; an example of mission descriptions is provided in Table 3.7.1.3-II. The disciplines listed in Table 3.7.1.3-III are a subset of SATS COMM1201 (materials processing) and SAAX307 (life sciences).

3.7.2 Internal Environment

3.7.2.1 Dimensions

The overall dimensions of the USL are shown in Figure 3.7.2.1-1. Figure 3.7.2.1-2 shows a cross-section of the module indicating a 4-stand-off configuration with floor, ceiling and wall racks installed. The rack envelope used for this arrangement is shown in Figure 3.7.2.1-3. The module hatch dimensions are shown in Figure 3.7.2.1-4.

3.7.2.2 Atmosphere

The USL will be maintained at a comfortable "shirtsleeve" environment. Figure 3.7.2.2-1 shows the respirable atmosphere and water requirements for the module.

3.7.2.3 Microgravity

Microgravity is a tangible resource of the Space Station and is described later. There are features of the Space Station operation which affect the quality of the microgravity environment as follows:

3.7.2.3.1 Effects of External Activities

3.7.2.3.1.1 Centrifuge Vibration

The science lab includes a variable-g centrifuge for 1-g controls and various experiments on effects of fractional and zero gravity on living things. Centrifuge vibration, if the centrifuge is not vibration-free, will affect several activities as noted on the matrix. The centrifuge must be designed to be nearly vibration-free by, for

example, being designed to rotate about its center of mass using a magnetic rim drive. Also, the centrifuge, unless its axis of rotation is perpendicular to the orbit plane, will introduce gyro torques unless counter-rotating compensating mass is used.

3.7.2.3.1.2 Incompatibilities Caused by Satellite and Platform Servicing

Microgravity disturbances will be handled by scheduling. Refueling hazards and contamination will be handled through suitable accommodations design and operations planning.

3.7.2.3.1.3 Incompatibilities Caused by Shuttle Operations

Periodic shuttle visits may introduce center of gravity shifts, other microgravity contamination, and release contaminants due to operation of shuttle attitude control and maneuver thrusters. Since the visits are periodic, microgravity contamination is subject to scheduling. The present space station design places shuttle berthing close to the c.g. in order to minimize steady-state contamination of the microgravity environment. This is particularly important in the man-tended case. Maneuver design and proximity operations planning are expected to reduce thruster contamination to an acceptable level.

3.7.2.3.1.4 Incompatibilities Caused by Large Space Structures Technology Development Operations

Severity of operations vibrations introduced by these missions needs to be assessed. Because these operations may be of extended duration, scheduling is not necessarily an appropriate mitigating strategy. Large projects typical of "growth" space station operations may introduce

TABLE 3.7.1.3-I NEAR-, MID-, FAR-TERM STATION ACCOMMODATION TEST SETS (SATS)

Near-term SATS (IOC)				
Set 1	Set 2	Set 3	Set 4	Set 5
COMM1201	SAAX0307 COMM1202	SAAX0307 COMM1203	COMM1201 COMM1202 COMM1203	SAAX0307 COMM1201 COMM1202 COMM1203
ESA(Group 1) Japan US Canada	ESA (Group 2) US Canada	Japan US	ESA (Group 1) Japan US Canada	ESA (Group 2) Japan US Canada
Mid-term SATS (Growth beyond IOC)				
Set 1	Set 2	Set 3	Set 4	Set 5
COMM1201 COMM1202 COMM1203 COMM1204	SAAX0302 SAAX0303 COMM1202 COMM1203 COMM1206	SAAX0307 COMM1201 COMM1202 COMM1203 COMM1204	SAAX0307 COMM1201 COMM1202 COMM1203 COMM1204 COMM1206	SAAX0302 SAAX0303 COMM1201 COMM1202 COMM1203
ESA Japan US Canada	ESA US Canada	Japan US Canada	ESA Japan US Canada	ESA Japan US Canada
Far-term SATS (Indefinite)				
Common test set				
COMM1201 COMM1202 COMM1203 COMM1204 COMM1206	SAAX0302 SAAX0303 SAAX0305	ESA Japan US Canada		

TABLE 3.7.1.3-II CONTENTS OF NEAR-TERM SATS SET #1

COMM 1201	<u>MPS Laboratory</u> - Laboratory module for materials processing science, applications and commercial research, development and demonstration.
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ESA missions (Group 1)

LIF111	<u>General purpose of Life Research Facility</u> - Research will cover cellular biology; plant physiology; human and animal (small rodent) physiology; preliminary investigations in eclss; preliminary feasibility demonstration of bioprocessing techniques and protein crystal growth.
LIF311	<u>EXO- and Radiation Biology Development</u> - A co-orbiting platform covering the fields of exo-biology and radiation biology; developmental and generic biology of plants, insects and small organisms recurring very low g-levels, high volume and variable radiation requirements.
MAT130	<u>Automated Materials Processing</u> - Production of industrial materials.
TO235	<u>Robotic Servicing Experiment</u> - To demonstrate validity of 2 European servicing concepts applicable in Columbus Phase 2: A) Servicing of unmanned platform by a servicing vehicle mounted-manipulator. B) Servicing of man-tended platform by a hermes-type spaceplane-mounted manipulator.
TO236	<u>Fluid Transfer Management</u> - To demonstrate validity of on-orbit fluid transfer management system (FTMS) concept applicable in Columbus Phase 2 and other future European space programs: A) Transfer of storable and cryogenic propellants. B) Transfer of pressurized gases.
TO241	<u>Large Structure Dep/Ass.</u> - To demonstrate validity of structural concepts for large antennas, concentrators, supporting structures including inflatable solar radiation concentrators, inflatable antenna and primary structure.

Japanese missions

C-001	<u>RFI</u> - To provide design data of RFI for the space station due to the electro-magnetic transmissions from free flyers and ground.
L-001	<u>Biology and Medicine</u> - To acquire the knowledge on the subchronic and chronic effect of space environment on the living organism, based on the information generated.
L-002	<u>Space Medicine</u> - To increase understanding of the effect of space environment on the physiological, psychological and behavioral performance of human beings.
L-003	<u>CELSS</u> - To develop fundamental knowledge on the physiology of plants and algae under space environment.
L-004	<u>Biotechnology</u> - To develop space manufacturing technology based on the electrophoretic separation under microgravity seeking possibilities to use biological processes for producing valuable materials in space environment.

TABLE 3.7.1.3-II CONTENTS OF NEAR-TERM SATS SET #1 (Cont'd)

Japanese missions

M-001	<u>Material Science Experiment</u> - To contribute to the promotion of such basic material sciences as fluid dynamics, diffusion, chemical reaction, solidification and deposition, with unique equipment.
M-002	<u>Space Processing for Advanced M</u> - Use space environments to develop and establish space processing technology
S-003	<u>High Energy Cosmic Rays</u> - To detect high energy electrons (10^{12} EV) and high energy heavy nuclei in cosmic-rays with energies of 10^{13} - 10^{12} EV)
S-004	<u>Cosmic Gamma Ray Bursts</u> - To observe gamma ray bursts in various energy regions.
T-001	<u>Space Environment Test</u> - To obtain basic engineering data of materials, components and units applied in space to evaluate their compatability required for design integrity.
T-005A	<u>Space Robotics - Step 1</u> - To develop and verify the technology required for space robotics.
T-005B, 5C	<u>Space Robotics - Steps II and III</u> - Same as T-005A.
T-009	<u>Liquid Propellant Handling</u> - Research and development in fundamental behavior, functional and performance characteristics of liquid propellant storage and refueling for on-orbit transport vehicles.

US missions

SAAX0001	<u>CRNE</u> - To study the characteristics and distributions of galactic cosmic ray propagation through interstellar space
SAAX0004	<u>Shuttle Infrared Telescope Facility (SIRTF)</u> - 28.5 attached mission: To conduct definitive high-sensitivity infrared photometric and spectroscopic studies of a wide range of astrophysical phenomena.
SAAX0011	<u>Advanced Solar Observatory (ASO)</u> - 28.5 attached mission ASO will carry individual instruments capable of examining solar phenomena that can be pointed to regions of interest on the solar disc or throughout its atmosphere. The ASO consists Pinhole/Occulter, and the Solar Optical Telescope.
SAAX0012	<u>Hubble Space Telescope Servicing (ST)</u> - 28.5 free flyer mission. The objectives are to learn of the evolution of stars, of ours and other galaxies, and to explore Quasars, Pulsars, Gas Clouds and other planets.
SAAX0013	<u>Gamma Ray Observatory Servicing (GRO)</u> - 28.5 free flyer mission: To investigate cosmic sources of gamma rays in a survey and in special investigations.
SAAX0016	<u>Solar Small Physical (SMM)</u> - 28.5 free flyer mission: To investigate causes and effects of solar flares.
SAAX0017	<u>Advanced X-Ray Platform (AXAF) Servicing</u> - 28.5 free flyer mission: X-ray astronomy research in the areas of Resource Location and Structure Spectroscopy, Polarimetry, and Temporal Behavior.

TABLE 3.7.1.3-II CONTENTS OF NEAR-TERM SATS SET #1 (Cont'd)

US missions

SAAX0022	<u>Space Station Spartan Platform 1</u> - For low cost astrophysics and space science payloads to perform scientific investigations and test new instruments and concepts. Low cost, minimum turn around is a prime objective.
SAAX0023	<u>Space Station Spartan Platform 2</u> - Same as SAAX0022.
SAAX0026	<u>Leased Platform 1 (Explore)</u> - Explorer missions are low cost for special astrophysics, space plasma physics, and atmospheric investigations from space. The first payload would be XTE.
SAAX0027, 28, 30, 31	<u>Leased Platforms 2.3.5 and 6 (Explorer)</u> - Same as SAAX0025 above.
SAAX0207	<u>Solar-Terrestrial Observatory</u> - 28.5 attached payload for space station. The observatory objectives are to study Space Plasma/Atmospheric interactions using observations of natural and induced atmospheric emissions and to exploit the natural plasma laboratory of space. The SPP Payload contains the following instruments: Wave injection (WISP), SEPAC, Low Light TV (AEPI), X-Ray Telescope (AXET), UV & Visible (ISO). Subsatellites (PPOP) and Multiprobes (MP) are included. The integration hardware includes an active thermal control loop, a shelf for mounting the SEPAC Electron Gun, MPO Arcjet, and instruments, and a special structure for mounting the WISP Dipole Antenna. The SPP is packaged on a Spacelab Pallet.
SAAX0250	<u>hitchhiker4-Earth Radiation</u> - To sample the radiative output of the tropics as a function of time of day.
SAAX0251	<u>Tropical Rainfall Explorer Pkg</u> - Three measuring instruments.
TDMX2011	<u>Space Materials & Coatings</u> - To provide a technology base for the development of advanced structural and insulating materials, optical, thermal, absorbing coatings, and diverse hardware components for long-term use in the space environment.
TDMX2132	<u>Advanced Radiator Concepts</u> - To evaluate and technically assess advanced radiator concepts with the test bed in actual space environment under operating conditions.
TDMX2153	<u>Solar Dynamic Power</u> - To provide a dedicated area on space station for-flight evaluation and test operation of candidate solar dynamic power systems, subsystems, and components. The flight evaluation work would be separate and apart from the operational power systems providing power to the station.
TDMX2311	<u>Long-Term Cryogenic Fluid Storage</u> - Attached mission: To advance the technology base for fluid acquisition, gauging, transfer and long term storage of both cryogenics and earth-storables under reduced gravity conditions. Also technology development to produce long-term cryogenic storage using insulation and refrigeration/liquefaction systems.
TDMX2411	<u>Advanced Adaptive Control</u> - Local Free-Flyer Mission. To develop and evaluate sensing strategies and mechanization for performance and stability improvement; subroutines for control gain update and reconfiguration schemes; adaptive control algorithms to validate distributed control hardware, algorithms and systems for active vibration damping, cooperative payload pointing, modular control, control during deployment, and precision point.g

TABLE 3.7.1.3-II CONTENTS OF NEAR-TERM SATS SET #1 (Cont'd)

US missions

TDMX2421	<u>Active Optic Technology</u> - Local Free-Flyer and Attached Mission: To provide a technology base for the construction, operation and control of large-aperture segmented mirrors having high surface accuracy optical figure. Also to determine the feasibility of controlling shape distortion by on-board heating.
TDMX2441	<u>Guided Wave Optics Data Sys Expt</u> - To allow operation in a realistic space environment the optical and opt-electronic components of advanced high-data-rate fiber optic and integrated optic data systems in order to establish space worthiness of the technology, including data bus technology and data transmission in the microwave bandwidth region.
TDMX2472	<u>Advanced Automation Technology</u> - (to be defined) Development of an expert system with applied AI technologies for the automation of operational crew/payload interfaces.
TDMX2572	<u>Cryogenic Propellant Transfer/Stow/Reliquify</u> - To test and verify the hardware and techniques for reliquification of cryogenic propellant boil-off and to establish an accurate data base for performing reliquification over long durations in space.
TDMX2573	<u>OTV docking and berthing</u> - To provide a technology base for dock and berth capability of a space-based OTV at a space station.

Canadian missions

SAAX4002	<u>POLCATS</u> - To monitor firegin absorption agents near the space station or space platforms. These agents may be caused by material breakdown under solar radiation.
SAAX4004	<u>Long Base Line Array</u> - An extension of Canadian long base line array with a large space antenna to detect new astronomical sources of radio emissions.
SAAX4006	<u>UV Atmospheric Limb Scanner</u> - Quantitative measurement of altitude profiles of aeronomically significant species by solar occultation and/or atmospheric emission observations.
TDMX2400	<u>Radars (Station)</u> - Development of radar systems
TDMX4002	<u>Sensor (Station)</u> - Ice and Earth monitoring, radars, vir, scatterometers, etc.
TDMIX4003	<u>Solid State Memory</u> - Evaluation of damage to solid state computer memories to develop radiation hardness computers and hardware.
TDMX4004	<u>Solar Cells</u> - Development of high power solar cells and reconditioning tests.
TDMX4005	<u>Polymer Matrix Composites</u> - To evaluate damage and deterioration of composite materials in the space environment.
TDMX4006	<u>Space Structures</u> - To evaluate the deployment, cotnrol, retraction and maintenance of such large space structures as antennae.
TDMX4007	<u>Mapping Cameras (Station)</u> - Develop tests of automatic mapping cameras and film recovery procedures.

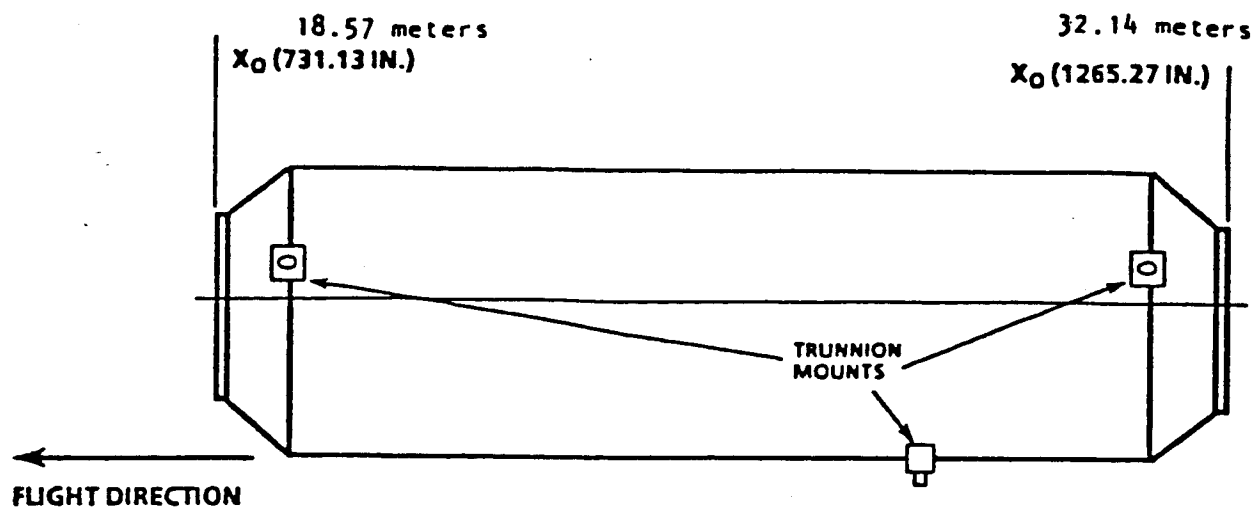
TABLE 3.7.1.3-II CONTENTS OF NEAR-TERM SATS SET #1 (Concluded)

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TABLE 3.7.1.3-III EXAMPLES OF EXPERIMENT THEMES, BY DISCIPLINE

Electronic materials
<p> Aligned magnetic composites Bridgman growth Bulk crystal growth Convection/diffusion transfer Crystallization phenomena Directional solidification Electroepitaxial crystal growth Float zone crystal growth Float zoning of II-IV materials Float zoning of III-V materials Float zoning of silicon Gradient band-gap semiconductor materials Gradient index materials Growth of II-VI crystals Growth of III-V crystals Hg-Cd-Te casting Layered systems/phase separation composites Liquid phase epitaxy Magnetic composites Organic conductors Other alloy type semiconductor casting Semiconductor production Solution crystal growth Supercooling phenomena Synthesis of silicon dihalides Synthesis of silicon suboxides Ternary semiconductors Thin film crystal growth Vapor phase crystal growth </p>
Biomedicine
<p> Metabolic balance for Ca and other bone-related constituents Bone density measurements Measure of renal stone risk factors Effect of microgravity on skeletal growth Full assessment of the hemodynamic alteration Dysrhythmia assessment Measurement of inflight neuromuscular activity Measurement of neuromuscular potential output during spaceflight Determination of neuromuscular fatigability of muscles during spaceflight </p>

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• OVERALL LENGTH	13.57 M (534.14 IN)
• OUTSIDE DIAMETER	444.5 CM (175 IN)
• INSIDE DIAMETER	421.6 CM (166 IN)
• CYLINDER LENGTH	1179 CM (464.14 IN)
• STS ATTACH FITTINGS	4 TRUNNION, 1 KEEL
• TRUNNION STATION	TBD

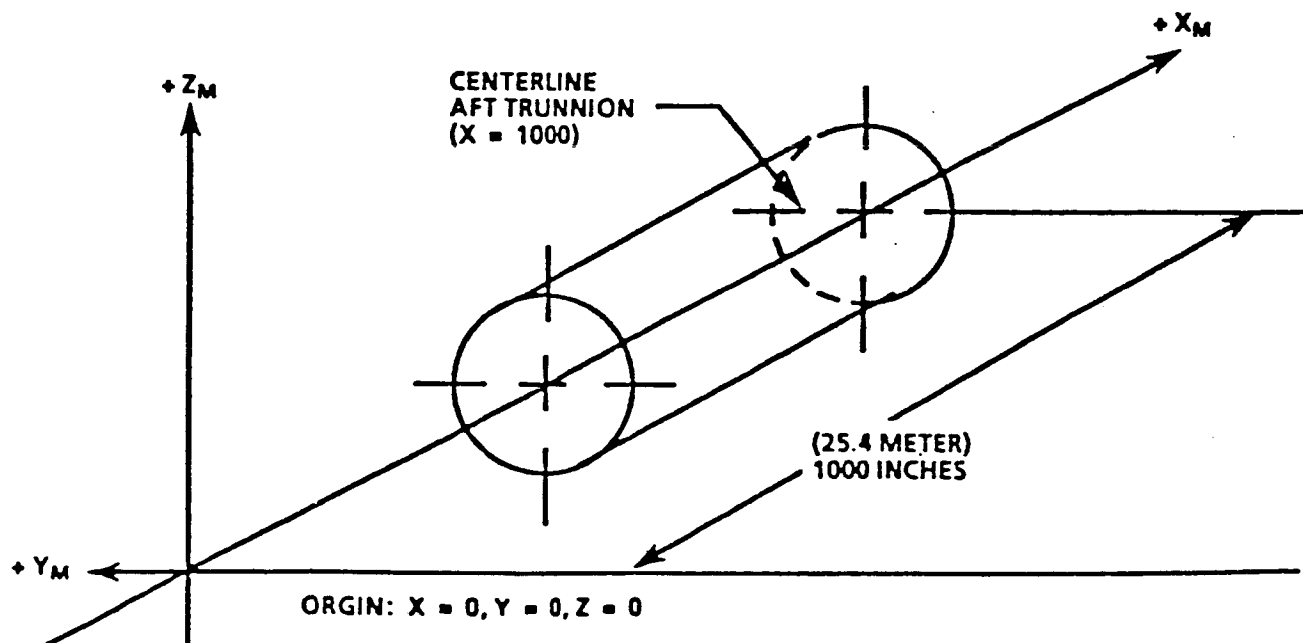


FIGURE 3.7.2.1-1 USL MODULE DIMENSIONS

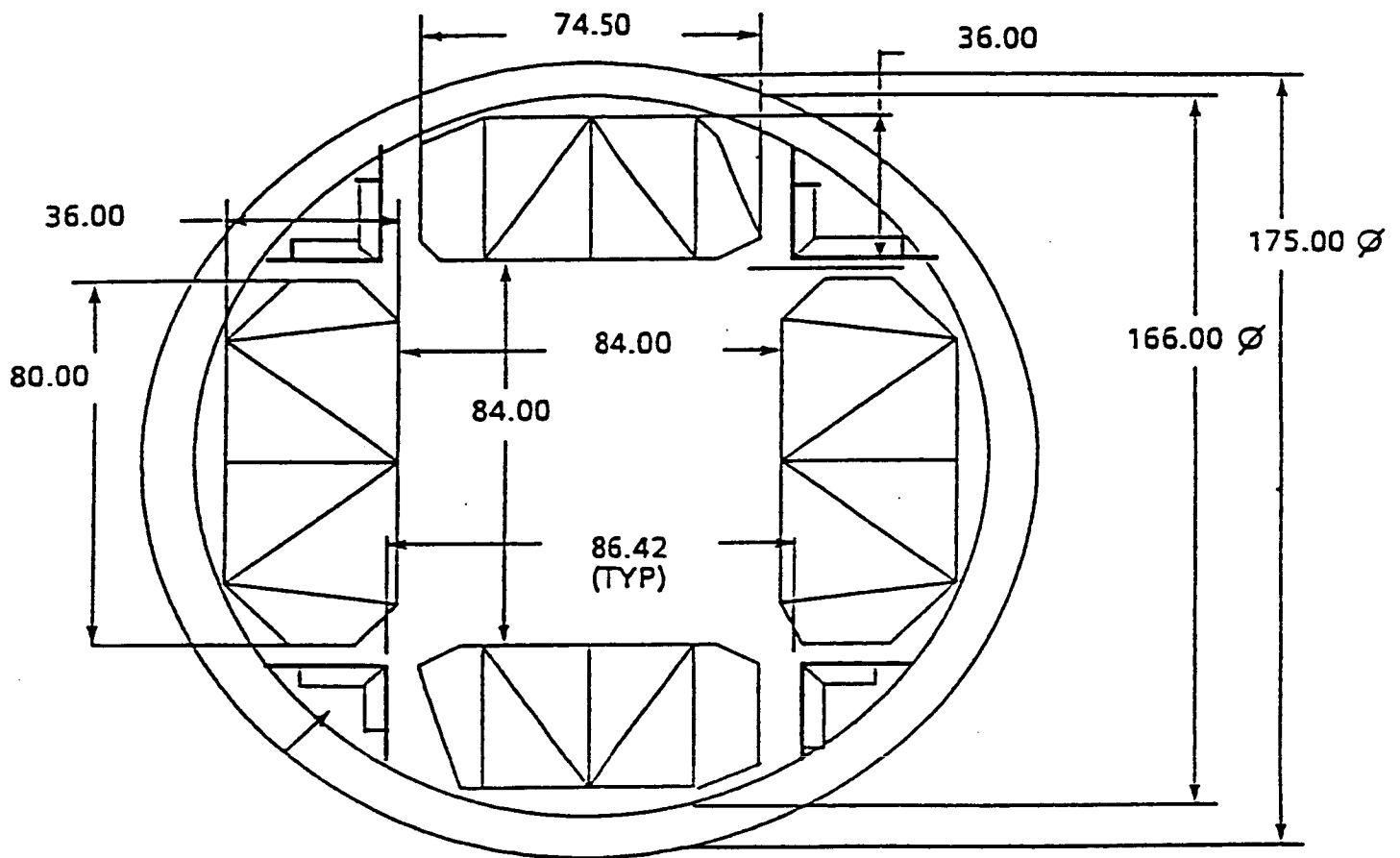
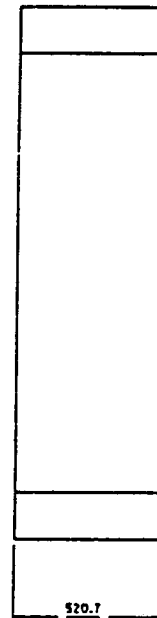
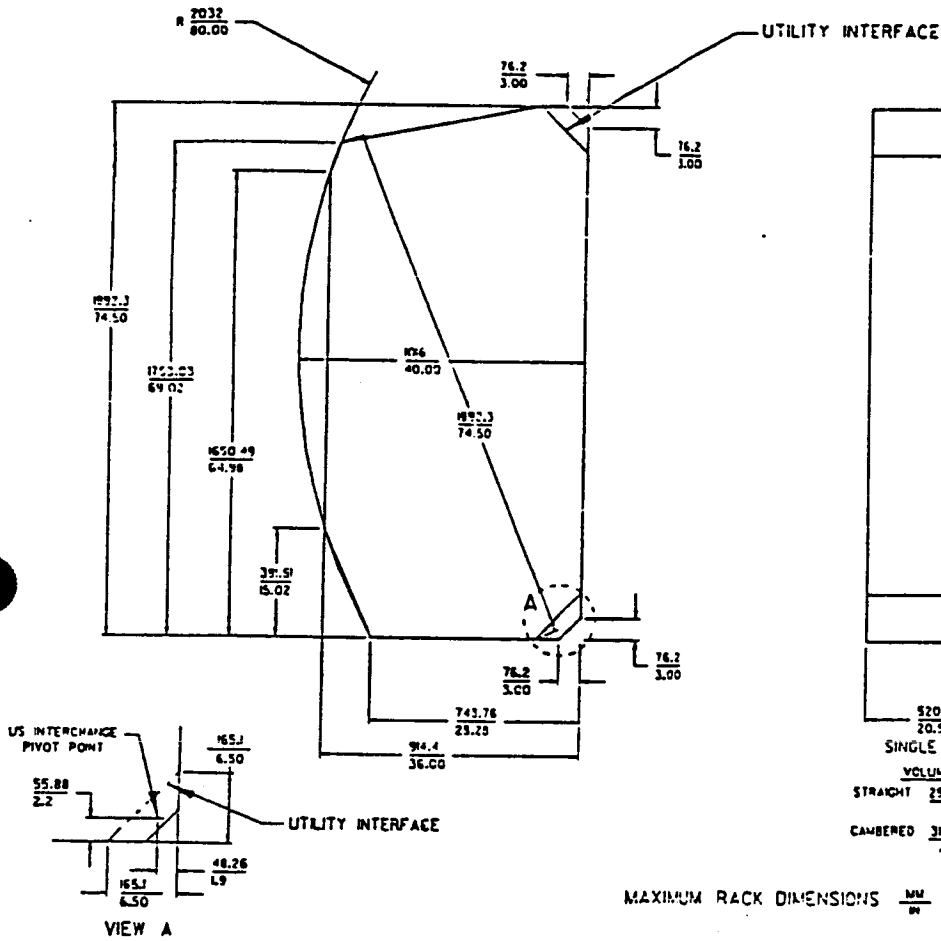
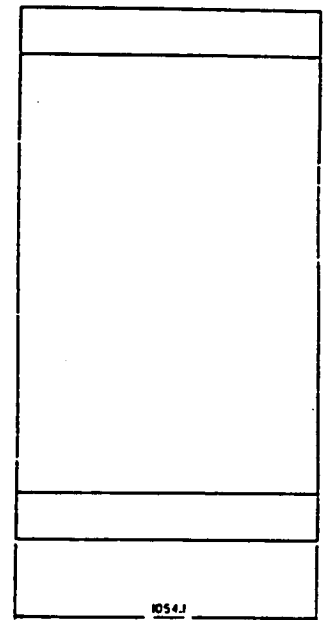


FIGURE 3.7.2.1-2 USL MODULE CROSS-SECTION



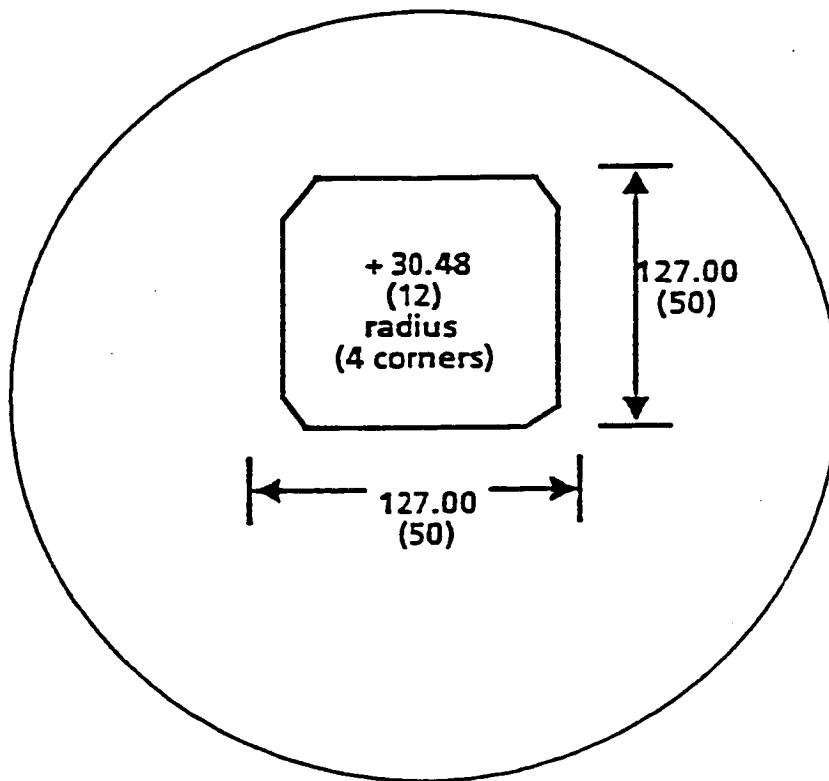
SINGLE WIDTH
VOLUMES
 STRAIGHT $\frac{29.67 \text{ CU FT}}{.84 \text{ CU M}}$
 CAMBERED $\frac{31.31 \text{ CU FT}}{.88 \text{ CU M}}$



DOUBLE WIDTH
VOLUMES
 STRAIGHT $\frac{60.07 \text{ CU FT}}{1.70 \text{ CU M}}$
 CAMBERED $\frac{63.40 \text{ CU FT}}{1.80 \text{ CU M}}$

MAXIMUM RACK DIMENSIONS $\frac{MM}{IN}$

3.7.2.1-3 STANDARD RACK DIMENSIONS



Dimensions in CMS (ins)

FIGURE 3.7.2.1-4 USL HATCH DIMENSIONS

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED (1)	28-DAY EMERGENCY
CO ₂ PARTIAL PRESSURE	N/m ²	400 max	1013 max	1600 max
TEMPERATURE	°K	291.5-297.1	288.8-302.6	288.8-305.4
DEW POINT (2)	°K	277.6288.8	273.9-294.3	273.9-294.3
PORTABLE WATER	kg/man-day	3.1-3.7	3.1 (3)	3.1 (3)
HYGIENE WATER	kg/man-day	5.44 (3)	2.72 (3)	1.36 (3)
WASH WATER	kg/man-day	12.7 (3)	6.35 (3)	0
VENTILATION	m/sec	.076/.203	.051/.508	.025-1.016
O ₂ PARTIAL PRESSURE (4)	N/m ² x 10 ³	19.5-23.1	16.5-23.7	15.8-23.7
TOTAL PRESSURE (5)	N/m ² x 10 ³	99.9-102.7	99.9-102.7	99.9-102.7
DILUTE GAS	---	N ₂	N ₂	N ₂
TRACE CONTAMINANTS (8)	mg/m ³	TBD	TBD	TBD
MICRO-ORGANISMS	CFU/m ³ (6)	500 (7)	750 (7)	1000 (7)

NOTES:

- (1) Degraded levels need "fail operational" criteria
- (2) Relative humidity shall be within the range of 25-75 percent
- (3) Minimum
- (4) In no case shall the O₂ partial pressure be below 15.0 N/M² (2.3 psia) or the O₂ concentration exceed 23.8 percent of the total pressure at 14.7 psia or 30 percent of the total pressure at 10.2
- (5) All systems shall be compatible with both 10.2 and 14.7 psia total pressure
- (6) CFU - Colony Farming Units
- (7) These values reflect a limited base. No widely sanctioned standards are available
- (8) Based on NHB 8060.1B (J8400003)

FIGURE 3.7.2.2-1 RESPIRABLE ATMOSPHERE/WATER REQUIREMENTS

c.g. shifts as well as large changes to station inertial properties. Consequences are not well defined. Crew hazards deriving from assembly operations will be controlled by mission/payload and support equipment design and operations planning.

3.7.2.3.5 Summary

Suitable design, operational, and scheduling strategies have been identified to mitigate the effects of mission and operations incompatibilities except in the case of large space structures missions where information is presently insufficient to obtain meaningful results.

3.7.2.4 Noise, Vibration and Lighting

There are a variety of design requirements which must be met by the final design of the USL interior, for the benefit of the crew inhabiting the Space Station. These requirements will define the ambient environment of the USL interior. The USL might also have a set of windows to space at one end of the module.

Ambient lighting and noise do not present a substantial problem for the customer who wishes to control the noise and light levels inside their rack. Vibration is an issue for customers who require isolation of a sensitive payload.

3.7.2.5 Radiation

Module hull material and thickness, equipment rack density, orbital inclination and Space Station altitude will determine the astronaut exposure to radiation from the sun, the Van Allen belt and deep space. Astronaut exposure data provide a measure of exposure to plants, animals and payloads inside the module. The primary contribution to the radiation environment inside the USL will be the constant flux of protons trapped within the Earth's magnetic field which are most concentrated

when the Space Station orbits through the South Atlantic Anomaly. This anomaly in the Earth's magnetic field results in a closer sweep of the main stream of fluxing protons towards the Earth's surface. Anything on an orbital path through this area is exposed to a much higher concentration of protons. Typically, in an orbit having a 30 degree inclination, the object will spend about 15 minutes per orbit inside the anomaly, for four orbits out of each sixteen. Trapped electrons are also more densely concentrated in the anomaly but will not penetrate into the module. Electrons are also trapped in the Earth's magnetic field and are encountered in the anomaly region. Electrons are encountered in orbits that are nearly equatorial but are present at greater densities in the more polar inclinations which pass through the auroral zones. Electron bombardment can affect externally exposed electronic components but do not affect life inside the module.

The Space Station will orbit far below the Van Allen radiation belts. Cosmic radiation is attenuated by the Earth's magnetosphere. Solar cosmic rays fluctuate with burst activity on the surface of the sun and during a solar flare will penetrate the Earth's magnetosphere. Radiation dosage requirements are designed to protect crew members at Space Station and can also be used to assess effects upon payloads.

3.7.3 External Environment

Features of the external space environment that might be of some concern to customers with plans for exposure of a payload item to this environment are as follows: 1) material corrosion by atomic oxygen, 2) bombardment of electronics by low-level electrons, and 3) orbital debris. Atomic oxygen is generated by the bombardment of oxygen molecules in the Earth's atmosphere. At 440 km (240 nautical miles) altitude atomic oxygen is pre-

sent at concentrations between a minimum of 107 and a maximum of 109 atoms per cubic centimeter. This would be a very low density except that objects moving at orbital velocities react with enough atomic oxygen at significant energy to result in degradation of certain materials. Orbital debris from human activities is expected to increase through the next decade and is present in greater densities than meteoroids. The probability of impact by particles between one and ten cm has been considered in the design of Space Station and there are crew response procedures in the event of an impact.

3.7.4 Resources

3.7.4.1 Volume Restraints

The basic element of the available volume in the USL is the standard equipment rack. The shape of the customer payload is determined by the rack dimensions and the requirements of EIA-STD-RS310C, which defines the 19 inch panel arrangement which is an element of rack design.

Customer payloads which do not adapt to standard racks will be accommodated provided that modularity in terms of rack basic dimensions are maintained. For payloads which do not meet the modularity requirements, a waiver from space station management will be required. In addition to the provision of rack space for customer payloads, volume will be provided for storage. All customer payloads will comply with the standard rack interface requirements.

3.7.4.2 Environment

The USL environmental control and life support system provides the crew with a habitable environment which will support eight members in a "shirt sleeve" atmosphere. The USL will provide temperature and humidity control, atmosphere control

and supply, atmospheric revitalization, fire detection and suppression, potable water recovery and management and contamination (trace gases, particulates, and fluid droplets) control and monitoring for the work volume. The temperature and relative humidity of the USL atmosphere during normal operation will be maintained between 18 and 27 degrees C and 25 to 75 percent relative humidity respectively, and will not be adjustable for experiment purposes.

3.7.4.3 Standard Racks

Standard racks also provide a set of utilities (or their provisions) which are interfaced through the rack connector plate which is located at every double rack increment (i.e., every 42 inches, nominal). These utilities include: 1)electrical power, 2)thermal rejection, 3)data management, 4)avionics cooling air, 5)fluids supply, 6)audio/visual communications, 7)vacuum process materials management.

3.7.4.4 Electrical Power

Space station electrical power at IOC is limited to 50kW for all customer requirements including line and conversion losses. Refer to appendix B for a description of the USL electrical distribution subsystem.

3.7.4.5 Microgravity

There are two steady-state, residual sources of acceleration on the USL which forms part of the Space Station orbiting at 250 nm altitude in an earth-pointing attitude:

- a. The gravity gradient which is a function of the distance from the center of the earth and center of gravity of the Space Station.
- b. Aerodynamic drag

(of which the gravity gradient is the largest)

The 3-dimensional form of the gravity gradient acceleration level is an elliptical cylinder which is centered at the Space Station center of gravity and open along the flight path. Gravity cancels the centrifugal acceleration along the line represented by the orbital trajectory of the Space Station center of gravity.

There remains a steady-state acceleration level at the center of gravity which is the minimum acceleration level available as a resource to the USL. The USL module is located close to the center of gravity to take advantage of this resource.

In addition to the steady-state accelerations, random or periodic, low frequency accelerations are imposed on the USL through such actions as crew activity, rotating machinery, reboost and shuttle docking.

To alleviate the problem of low-frequency accelerations, it may be necessary to place those experiments requiring very low levels of gravity on a free-flying platform outside the influence of such accelerations.

3.7.4.6 Thermal Control

The rejection of waste heat from customer payloads will be accomplished by one or more of several means. The three principal methods that will be employed are: 1) liquid coolant loops, 2) avionics air cooling and 3) cooling by consumables.

3.7.4.7 Data Management

The USL data management system will provide such things as:

1) data distribution, 2) man-machine interfaces, 3) status displays, 4) data stor-

age and retrieval, 5) data acquisition, process and control and 6) caution and warning annunciation.

3.7.4.8 Laboratory Support Equipment

As a part of the resource provisioning of the USL, certain items of support equipment will be manifested according to the needs of the mission payload set. This equipment will be selected from the list of requirements provided by the USL and customers from their functional analyses. Where items of equipment are of such a general nature and in frequent demand, they will be installed as part of the USL baseline configuration and although subject to change-out as circumstances dictate, will remain a permanent part of the USL. An example is the glove box.

Other items that are in less demand but required by and shared by a number of users, will be provisioned and changed out according to the mission schedule. Where support equipment is of a specific nature and peculiar to single customers, it will be provided by that customer and installed to support his immediate needs.

3.7.4.9 Crew Time

Crew time at IOC will be the most important and limited resource available for the conduct of experiments. Customers should expect that with the variety and number of facilities requiring crew time at IOC and in subsequent mission sets, that their procedures and troubleshooting documents should be written to a level that is easily read by laboratory technicians.

3.7.4.10 Vacuum

A low-level vacuum is provided for general customer use and is a closed-end system employing pumps and storage tanks. It offers the means of moving waste gases

from payload cavities and the provision of insulation in jacketed devices such as furnaces. Vacuum levels in excess of the milli-torr provided by this resource will be the responsibility of the customer. The connection of customer facilities to outer space vacuum will be for emergency purposes only or by special dispensation of the Space Station management.

3.7.4.11 Process Materials Management

The Process Materials Management System (PMMS) is provided to ensure the safe handling, processing and transportation of all materials used by the customers in the operation of their equipment. The design of equipment and processes will include the requirements and limitations set by the PMMS so as to ensure the safety of the crew and the space station.

3.7.4.12 Stowage

A portion of the USL volume is set aside for the purpose of storing items which are not normally required to be placed in experiment or subsystem racks. These items will include such things as wipes, syringes and other consumables. Spare parts and inert supplies for experiment equipment are provided for in general storage accommodations. Special storage for experiment samples and supplies will be provided by the refrigerator and freezer, EMI-shielded lockers and other facilities as necessary. The need for storage and the ease of access will be identified in the functional analysis of the customer experiment.

3.7.4.13 Audio/Visual Communications

The USL will provide users with two-way audio and visual communication between the module and other space station elements, within the module, and between the module and earth terminals. Standard TV transmission will be provided for up

and down-linking video data. Provision will be made to store audio and visual data.

3.7.4.14 Fluids

Certain fluids and gases will be provided for users of the USL.

3.7.5 Safety

The intent of this section is to emphasize payload safety and assist the payload developer in achieving compliance with the payload safety requirements of NASA.

The USL will support many different types of payloads which will use the Space Transportation System (STS) as the carrier into space. For the mutual benefit of all organizations using the Space Station/USL/STS, it will be necessary that all experiment equipment, including new design, existing design (reflown equipment) and Ground Support Equipment (GSE) meet documented, specified requirements to ensure operational safety. The purpose of the Safety System Program is to control or eliminate hazards to crew and equipment during integration during both flight and ground operations.

3.7.5.1 Safety Requirements

The Safety Requirements apply to experiment design and operations during flight and ground activities including transportation, test and checkout, installation and refurbishment. The NASA Headquarters document "Safety Policy and Requirements (SP&R) for Payloads Using the Space Transportation System (NHB 1700.7A)" establishes the official set of basic safety requirements for all payloads using the USL/STS. The thrust of the SP&R is to minimize USL/STS involvement in the payload design process while maintaining the assurance of a safe opera-

tion. The SP&R provides overall safety policies and requirements that must be complied with while allowing flexibility in the implementation approach.

3.7.5.2 Safety Management System

There are two distinct aspects of the Safety Management System; first, ensuring and certifying that each item of experiment is safe for flight, and second, ensuring and certifying the safety of the integrated laboratory.

Experiment Equipment – Safety concerns are precipitated by integrating and operating an entire laboratory. The experiment developer has the responsibility for equipment safety which extends from the manufacturer through flight test and cannot be delegated. All equipment suppliers will be required to certify safety compliance of their equipment to the USL integrator. However, to assist him, the USL integrator will review the design packages during scheduled design reviews to verify that the safety requirement provisions are incorporated into all End Item Specifications, System Specifications, Test Plans and procedures. Any safety requirements designated by NHB 1700.7A or the laboratory integrator that cannot be met shall be documented on a waiver request form and submitted to the USL integrator for disposition.

Laboratory Integration – The USL integrator shall be responsible for overall safety compliance. To ensure the integrated laboratory meets the overall station safety compatibility, a series of integrated laboratory reviews will be conducted. Overall experiment safety is an integral part of these reviews. The data required for these reviews include a hazard analysis performed by each experiment supplier, an assessment of these analyses and an inte-

grated hazard analysis performed by the laboratory integrator.

3.7.5.3 Safe Haven Provisions and Procedures

Emergencies are classed as (1) immediately life-threatening, (2) not immediately life-threatening, and (3) not life-threatening. Class 1 requires an immediate retreat from module affected by fire, explosion, hazardous chemical release or loss of pressure. Containment of the hazard and damage repair occur later. Class 2 might require retreat to a safe haven over a period of time in response to a loss of power, thermal control, ECLSS or a leak or other malfunction involving a non-toxic chemical. Loss of communications, data management or related emergencies (Class 3) might not require retreat to a safe haven.

Resources available during an emergency include a shower, about 120 gallons of water, habitable volume for seven crew members and a reserve supply of oxygen. The shower is designed to accommodate impaired function (blindness, other injury) during operation and can be activated by one person.

Each module provides low-level monitoring of habitability. Detection of contaminant levels is possible after module systems shut-down during an emergency or during systems start-up of a new module, before occupation by crew members.

3.7.5.4 Customer Responsibilities

Submittal of Safety Data – The experiment developers shall furnish safety data in support of their hardware acceptance reviews and the integrated laboratory reviews which shall be commensurate with

the experiment hardware maturity at the time.

3.7.5.4.1 Experiment Requirements Review

Submission of the following data is required at the Experiment Requirements Review.

- Equipment descriptive material (narrative descriptions, sketches, block diagrams, etc.)
- A complete safety matrix for each item of equipment.
- A complete hazard list for each subsystem checked on the safety matrix.
- A list of metallic (critical structures only) and nonmetallic materials.

Experiment Final Design Review – Submission of the following data is required at the experiment Final Design Review.

- A complete hazard report for each hazard title by subsystem with a unique sequential number for each report with attached description material such as block diagrams, schematics, etc.
- All descriptive material available for reconciliation of the hazard shall be attached to and submitted with the hazard report.
- Final plans for the verification and reconciliation of all hazards shall be indicated in the "Safety Verification Method" block of the hazard report.
- The supplier shall submit a final safety data pack, which contains all

test data, analyses, operations planning, or schematics required to close all hazards as designated in the controls and verification blocks and the applicable data specified in paragraph 305 of NHB 1700.7A.

- The developer/supplier shall execute the required certification form and forward it with the final safety submittal. All required updates to previously submitted data will be included.

3.7.5.4.2 Hazards Containment

It shall be a design requirement of the USL that hazardous materials not be admitted to the module environment. All potential hazardous materials shall be so contained that any plausible sequence of failures will not result in releasing them into the USL atmosphere or into any other piece of equipment not intended for that purpose. Containment designs shall include active monitoring devices to alert the crew of such failures.

The Safety System Program provides generic guidelines that will assist payload developers in the design and operational safety of their equipment.

Most of the hazard potential is related to the movement and storage of various liquids and gases needed for or generated by experimental processes. Oxygen under pressure presents a severe fire hazard requiring flow-limiting orifices and emergency shutoff valves to control leaks and line ruptures. All of the gases will be stored on the outside of the USL. Tank size is limited to one cubic meter. Tanks will be designed to leak before rupture. Hydrogen would also be stored under pressure and therefore not be a continual storage hazard during the IOC. Hydrogen,

oxygen and inert gas storage pressure (6,900 kPa = 1,000 psi) is one-half the standard for industrial storage. Nitrogen and helium are the only process fluids that will be stored cryogenically. Cryogenic storage and distribution is more difficult and complex than storage of gas and therefore presents a greater likelihood of failures. A primary hazard that accompanies LN₂ or LHe storage is the displacement of oxygen in the USL atmosphere in the event of a pipeline leak or rupture. Accumulations of liquid wastes not re-used at the Space Station will be small and will be returned to Earth during IOC. Liquid wastes not rendered non-reactive will include a wide variety of compounds and therefore include a wide spectrum of hazards in the event of storage or distribution failure.

Solvents and reagents stored prior to use consist of a wide variety of materials in quantities of less than about two liters each. These will be stored separately according to incompatibilities, in lockers kept at a slight negative pressure by a regulated vent to the outside of the USL. Removing these materials from the lockers presents a hazard especially if a leaking container is not detected before opening of the locker.

3.7.5.5 Process Hazards

Process fluids will be used inside gloveboxes (single containment) similar in design to those in Earth laboratories. A glovebox/work bench will be used for cutting, grinding and other processes that generate dust or particulates. Failure of the seal or gloves would contaminate the cabin atmosphere with hazards ranging from nuisance to extreme danger, depending upon the material involved.

Wastes generated during the conduct of experiments and related processes will be

vented to the process materials management system, where subsystems will separate such material as gases (propulsion system) and water (depyrogenizer before re-use), and reduce the reactivity of substances that cannot be re-used. Until these waste rendering processes occur, there are hazards related to the proper sequencing of the various experimental processes. Incompatible chemical wastes entering the waste vents at the same time could result in explosion, fire or failure of seals and valves.

3.7.6 Customer Relationships

A "USL User's Handbook" will be prepared to ensure that customer coordination is accomplished in a comprehensive, expeditious and "user-friendly" manner. As part of this process, the Space Station designers will provide such tools as mock-ups, system simulation layouts, trades and analyses, crew skill assessment and experiment functional analyses. Cooperation with User Advisory Groups and other groups representing the interests of the community will be maintained to ensure the optimum design for the USL and its procedures for operation.

The close proximity of customer payloads and the limited resources of the space station will require a high degree of cooperation among the participants. Resources such as electrical power, thermal rejection and data management are finite in nature and will be time-lined so as to provide the maximum efficiency of operation while maintaining a degree of flexibility. For these reasons, control of the conduct of experiments will be vested in the module management by means of the software provided for this purpose.

The provision of support equipment is done on the basis that, where possible, it will be shared by as many customers as

possible which will reduce the cost of operation for both the Space Station and its customers. Unscheduled operations will be at the discretion of the Space Station management.

3.7.6.1 Proprietary Operations

The requirements for protecting the proprietary rights of Space Station users are defined in the document titled, "Space Station Proprietary Operations Analysis". The primary purpose of that document is to define requirements for protecting payload proprietary rights of Space Station commercial customers. These protection requirements encompass both ground and on-orbit operations. Analyses have been conducted to develop options for satisfying the proprietary requirements and resolving the issues identified.

3.7.6.2 Access to Resources

Access to resources will be through the USL data management system. This is

necessary because of the complex nature of resource requirements and availability. The DMS will sequence the application according to the mission schedule and the types and rates of application of resources needed to complete the operation of customer payloads. Intervention in the sequence of events will be under the control of Space Station management.

3.7.6.3 International Participation

Where agencies outside the United States participate in the Space Station program and require accommodations from the USL, the necessary revisions to this document will be made. It is assumed that the requirements and provisions made herein apply to all participants but as acceptable changes are identified they will be made accordingly.

4.0 WP-01 TEST AND VERIFICATION PROGRAM

4.1 Overview

The WP-01 project for the Space Station Program is a multi-unit design and production program, with outfitting of the modules to unique end-item configurations. For the SDR definition of the IOC program, end item elements will be produced and outfitted as follows:

- United States Laboratory (USL) Module
- Habitat Module
- Logistics Elements, comprised of
 - Pressurized Module
 - Dry Cargo Unpressurized Carrier
 - Fluids Carrier
 - Propellants Carrier
- Airlocks, comprised of
 - Airlock
 - Hyperbaric Airlock
 - Resource Nodes

These element responsibilities are based on WP-01 assignment of the pressurized volume.

4.1.1 Verification Program Interfaces

The overall scenario for producing, integrating, and verifying the modules is as shown in Figure 4.1-1. From the figure, a typical DDT&E flow is shown (top of chart). The chart shows the simultaneous parallel tasks for development of (1) module systems, (2) outfitting systems, and (3) payload systems (development is assumed to be by the user community, and integration with the laboratory module to be included in WP-01 tasks). It is apparent that the program is complex in that a number of organizations have tightly interrelated

tasks. It is assumed that control of these development roles and relationships will require highly disciplined specification and ICD practices over the whole program.

4.1.2 Planning Precepts

The principal requirements for the WP-01 verification program are extracted from the specific requirements cited in PDRD JSC 30000 and SRD 0001.

- a. Design verification requires hardware and software certification/qualification and also system verification. See also item (c).
- b. Use protoflight philosophy when practical.
- c. System verification includes interface verification, hardware/software compatibility, system integration testing, prelaunch testing, and maintenance testing.
- d. Acceptance testing requires hardware and software testing to verify that they are built to design, performance is acceptable, and they are free from manufacturing defects.
- e. Verification systems and tasks in space is a significant non-recurring requirement that overlays initial operations.
- f. Verification of the self-test and self-monitoring capability that automates the station systems and frees the crew for productive user support tasks.

Features of the WP-01 test program that are planned in response to the above requirements are shown in Table 4.1-I.

4.1.3 Protoflight Philosophy

Implementation of the protoflight philosophy is a program requirement aimed at significantly reducing the test program's costs by reducing dedicated test articles. The use of protoflight philosophy implies that the traditional roles between design criteria and test criteria are conservatively adjusted so that testing for qualification (overstress testing) can be done on flight hardware without degrading its flight worthiness - but testing cannot be pushed to failure, so analytical means are required to determine the ultimate characteristics of the design. In order to have credible analytical capability, the models must have been previously verified. This can be done by examining comparable conditions on previous programs and filling in any open areas by testing on development hardware and selected test articles. Since model verification must precede its use with flight hardware, it is planned to begin early in Phase C/D with prototype hardware.

Boeing's general approach is to apply protoflighting at the element and/or the rack level. Hardware to be installed in the rack (ORUs, components, etc.) would be qualified to worst case (stringent) performance and environmental levels. Racks would be grouped into typical families for protoflight qualification testing on a one-time basis. After protoflight testing is completed, the hardware is refurbished (instrumentation removal, cleaning, etc.) as required to restore it to flight configuration and acceptance tested. Subsequent articles would be tested to acceptance levels.

4.1.4 Maintainability Demonstration

The following discussion outlines the preliminary maintainability verification, demonstration, and evaluation plan.

4.1.5 Maintainability Verification

The maintainability verification and demonstration for Space Station equipment is to be performed as part of and in coordination with system test and evaluation. Maintainability verification and demonstration will be conducted on the ground to the maximum extent possible and will make maximum practical use of analysis, vice physical test. The maintainability demonstration plan will be responsive to the Space Station Program Level B Maintainability Program Plan, maintainability requirements, the maintenance concept and maintenance environment, the planned skill levels, and the levels of maintenance to be demonstrated.

The verification and demonstrations conducted as part of, or in coordination with, development testing will be conducted at the contractor's facilities using contractor personnel and resources. Formal maintainability demonstrations conducted on pre-production or prototype hardware will be accomplished at either government or contractor facilities, using either customer or contractor personnel and resources, as deemed most appropriate for a given test. The contractor will assume the responsibility for planning, monitoring, data collection and analysis, and reporting; the government will monitor all activities.

4.1.5.1 Demonstrations

Demonstrations are normally carried out under actual operational conditions, or

TABLE 4.1-I KEY WP-01 VERIFICATION REQUIREMENTS AND CONCEPTS

Requirements	Features
Design Verification	Qualification of LRUs and ORUs Test articles repaired for downstream use in SIL Analysis required to evaluate performance
Protoflight Philosophy	Applied at element and task level Reduces dedicated test articles Tests are on flight hardware Complimentary analytical verification required
System Verification	Emphasis on simulators and tooling
Interface Compatibility	Verify simulators against flight articles
Hardware/Software Compatibility	Systems integration laboratory (SIL) Articles from other tests used Software compatibility an objective
Verification of Tasks in planned	Effective ground verification Space
Ground Verification of Interfaces with Flying Hardware	Results incorporated in basic design Previously verified simulators are a key to follow-on verification
Self-Test and Automated Operations	Built-in testability Embedded instrumentation Automated fault detection and redundancy management Use self-test capability for ground C/O

conditions which simulate closely the operational maintenance environment to the degree possible. For verification and demonstration of selected on-orbit maintenance tasks, test bed/mockups, zero-G aircraft, water tank, or STS flights may be needed in the conduct of the tests.

4.1.5.2 Test Sites

Specific locations for verification and demonstrations will be identified during detailed test planning. Sites will include the various contractor's plants, the NASA interface simulators and subsystem test beds, element mockups, and government and contractor software development facilities. Analyses to support maintainability evaluations will be conducted at the Boeing plant in Huntsville.

4.1.5.3 Facility Requirements

No new or dedicated (long term) facilities are planned specifically to support maintainability verification, demonstration and evaluation. Of existing government facilities, the MSFC Neutral Buoyancy Facility will be useful for development and demonstration of EVA maintenance procedures. Requirements for such facilities as zero-G aircraft and the STS will be avoided in favor of less costly alternatives.

4.1.5.4 Participating Agencies

Participation in demonstrations will include, as a minimum, Boeing and hardware/software vendors, MSFC technical and/or administrative personnel, and flight and/or ground operations representatives from other NASA centers. Customer participation, where appropriate, will be arranged by the test director through coordination with MSFC. Other participants or observers may be included at the discretion of the government and the test director.

4.1.5.5 Interfaces

The ILS elements to be considered will include maintenance planning, support and test equipment, supply support, transportation, handling and storage, technical data, facilities, and personnel training.

4.1.5.6 Maintenance Demonstration Conduct

The following items will be documented for each maintenance demonstration planned for the Space Station Program:

- a. Test objective
- b. Test schedules
- c. Test method, including accept/reject decision criteria, risks, etc.
- d. Data acquisition and analysis methods and procedures
- e. Specific data elements/maintenance tasks
- f. Units of measurement
- g. Type and schedule of reports
- h. Test team - Description of assigned responsibilities with qualifications, quantity, sources, training, and indoctrination requirements of team personnel will be provided for each major test activity. The test team organization will consist of the Test Director, technician personnel, maintenance personnel, operations personnel, and quality assurance personnel.

4.2 Verification Requirements Derivation

Requirements for WP-01 CEI elements are provided by the SRD, the CEIs, and

the ICDs. These presently exist in preliminary form that contain Section 3 performance requirements. Verification requirements allocation methodology is to be per Appendix C, Part 4.1, Section 3, of SS-SRD-0001 which specifies the Verification Cross Reference Index (VCRI) formats for flight system specifications and for GSE specifications.

A systematic methodology for making the allocation to Phase/Level/Method per Appendix C and a coordinated allocation to the hardware level of assembly is shown in Figure 4.2-1. The initial requirements task is that of determining allocations for VCRI (Bubble A). From the figure, the technique involves use of a Verification Allocation Work Sheet (Bubble B) to break each phase down for unique consideration. The formats for the VCRI and the worksheet are shown in Figure 4.2-2. To make these allocations in a configuration-specific way that considers the subsystem designer's role, a subsystem DDT&E Flow and an Indentured Equipment List (in preliminary form if still in work) is used.

An example of the subsystem DDT&E Flows (for Internal TCS) are shown in Figure 4.2-3. Essentially, they show the designer's theme of subsystem design and verification, with the relationships between tests and analysis. The flow treats separately the phases of development, qualification and acceptance - both installation and checkout and final buy off. With this information and an Indentured Equipment List, the designer, test engineer, and technical staff analyst can readily reach a consensus on verification by analysis versus test, the level of assembly for qualification testing, the criticality of the various items of hardware (which identifies key development testing requirements. The outputs of

this are used in two ways: (1) entries in the VCRI (that are backed up by Verification Allocation Worksheets) and (2) entries in the Equipment Test Requirements Matrix (see Figure 4.2-4). Additionally, when the designer uses mature hardware (already qualified and off-the-shelf), verification by similarity requires (per SRD 0001, Part 4.1, paragraph 3.4.4) documentation of a comparison between Space Station requirements and previous qualification conditions. If modification and/or additional qualification is required, the determination between delta qualification or complete qualification shall be made from assessments of cumulative or interactive effects of added performance and environmental conditions on the device.

From this requirements baseline (VCRI and Equipment Test Requirements), the planning of the tests, analyses, etc., proceeds in the groups that receive the assignments. There is a joint task between the designer, test engineer, and analyst to specify test requirements in terms of objectives, success criteria, conditions, parameter specification/limits, etc. From these, test engineering proceeds to work through a test team to carry out the testing.

4.3 Design Verification

Protoflight element and rack level tests are conducted on production-configured hardware to demonstrate that the designed and manufactured hardware conforms to specification requirements. In addition, planned qualification tests are conducted at component level and subsystem level. Together, these tests qualify the end item elements for operation, generally to environments that exceed maximum predicted levels within the specified environments.

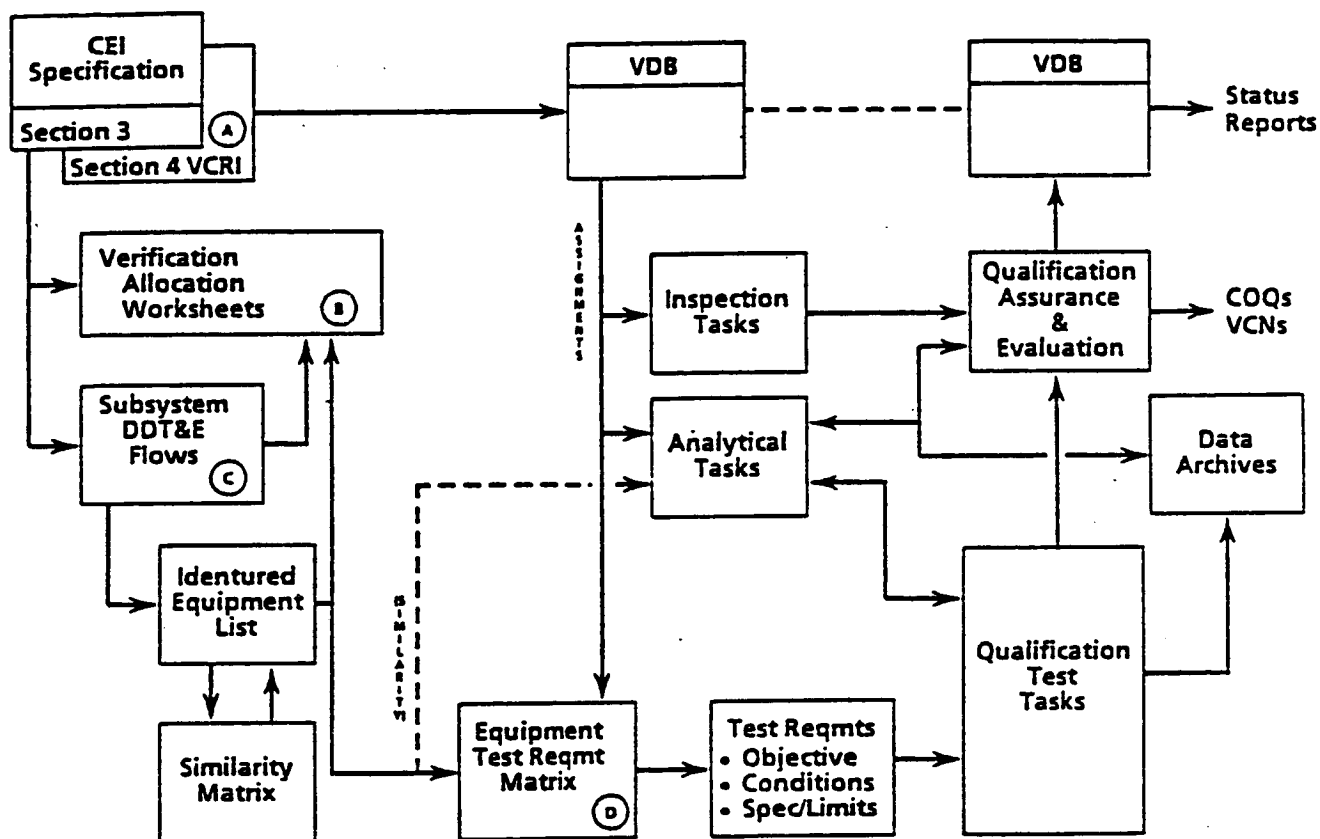


FIGURE 4.2-1 VERIFICATION REQUIREMENTS ALLOCATION METHOD

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VERIFICATION ALLOCATION			
PHASE	SUBPHASE	LOCATION	SOURCE REQUIREMENT: NOUN SS-SPEC-0100
			(B)
DESCRIPTION	CONTENTS (AND RATIONALE)		
A			
B			
C			
D			
E			
F			
G			
H			

EXAMPLE

VERIFICATION CROSS-REFERENCE INDEX												
END-ITEM: CODE: (PER 4.2.3)										CET SPEC NO.: X = NOT APPLICABLE		
SECTION 3.0 REQ NO & TITLE	N/A	A	B	C	D	E	F	G	H	REMARKS		
RETRNO CODES 1 - ANALYSIS (4.2.1.1) 2 - INSPECTION (4.2.1.2) 3 - DEMONSTRATION (4.2.1.3) 4 - TEST (4.2.1.4)										PHASE/LEVEL CODES A - DEVELOPMENT (4.2.2.1) B - ACCEPTANCE (COMPON/SUBASST) (4.2.2.2.1) C - CERTIFICATION (COMPON/SUBASST QUALIFICATION) (4.2.2.2.1) D - CERTIFICATION/ACCEPTANCE (INTEGRATED ASST/SUBSYS-PREINSTL) (4.2.2.2.2/4.2.2.3.2) E - CERTIFICATION/ACCEPTANCE (INTEGRATED MODULE/ELEMENT) (4.2.2.2.2/4.2.2.3.2) F - INTERFACE VERIFICATION (ELEMENT) (4.2.2.4) G - LAUNCH/RECOVERY STTE CHECKOFF (LAUNCH HAZ/TEST) (4.2.2.5) H - ON-ORBIT VERIFICATION (INTEGRATED END-ITEM) (4.2.2.6)		
<div style="position: absolute; bottom: 20px; left: 20px; border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; font-size: 1.5em;">A</div>										J		
										K		

FIGURE 4.2-2 VCRI AND VERIFICATION ALLOCATION FORMATS

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PHASE B	DEV.	QUALIFICATION	I&CO	ACCEPTANCE
Analytical Verification <ul style="list-style-type: none"> Internal Loop Model Development & Verification 	<ul style="list-style-type: none"> External Envir. Model Development & Verification Internal Loop Model Update 	<ul style="list-style-type: none"> External Environment Conditions Analytically Verified Internal Loop Test Data Analyzed for System and Element Qualification 	<ul style="list-style-type: none"> Rack Performance Data Analysis 	<ul style="list-style-type: none"> Element Performance Data Analysis
Testing <ul style="list-style-type: none"> Subscale Breadboard of Internal Loop (Off Shelf Components) Control Approach Tests 	<ul style="list-style-type: none"> Vendor Dev Testing Breadboard Update with Dev. Hardware Hardware Development Examples <ul style="list-style-type: none"> Pump Packages - Life Extension Scale-Up Digital Controlled Valves Disconnects Interface Heat Exchanger M&P Testing <ul style="list-style-type: none"> Coatings MLI Mapping of MLI Installations w/IR Scanners 	<ul style="list-style-type: none"> Vendor-Qualified Components System Qual Test Article <ul style="list-style-type: none"> User Internal Loop Single String System Built Up of Qual Hardware <ul style="list-style-type: none"> Performance Testing with <ul style="list-style-type: none"> User Loads Simulated Typical & Worst Case Timelines External Interface Heat Exchanger Interfaces with Simulated External Loop MLI/Panel System Test Article: <ul style="list-style-type: none"> MLI Section Meteoroid Rumper Thermal Control of Interior Site Thermal/Vacuum Testing for External Conditions Element Qualification by Performance Testing of Flight Modules (Protoflight) 	<ul style="list-style-type: none"> Vendor Acceptance of Components TCS Rack Functional Test Area with STE 	<ul style="list-style-type: none"> Performance Testing of Each Flight Module - <ul style="list-style-type: none"> Combined with Protoflight when Appropriate

FIGURE 4.2-3 TCS DDT&E FLOW SHEET 1 OF 2

C-2

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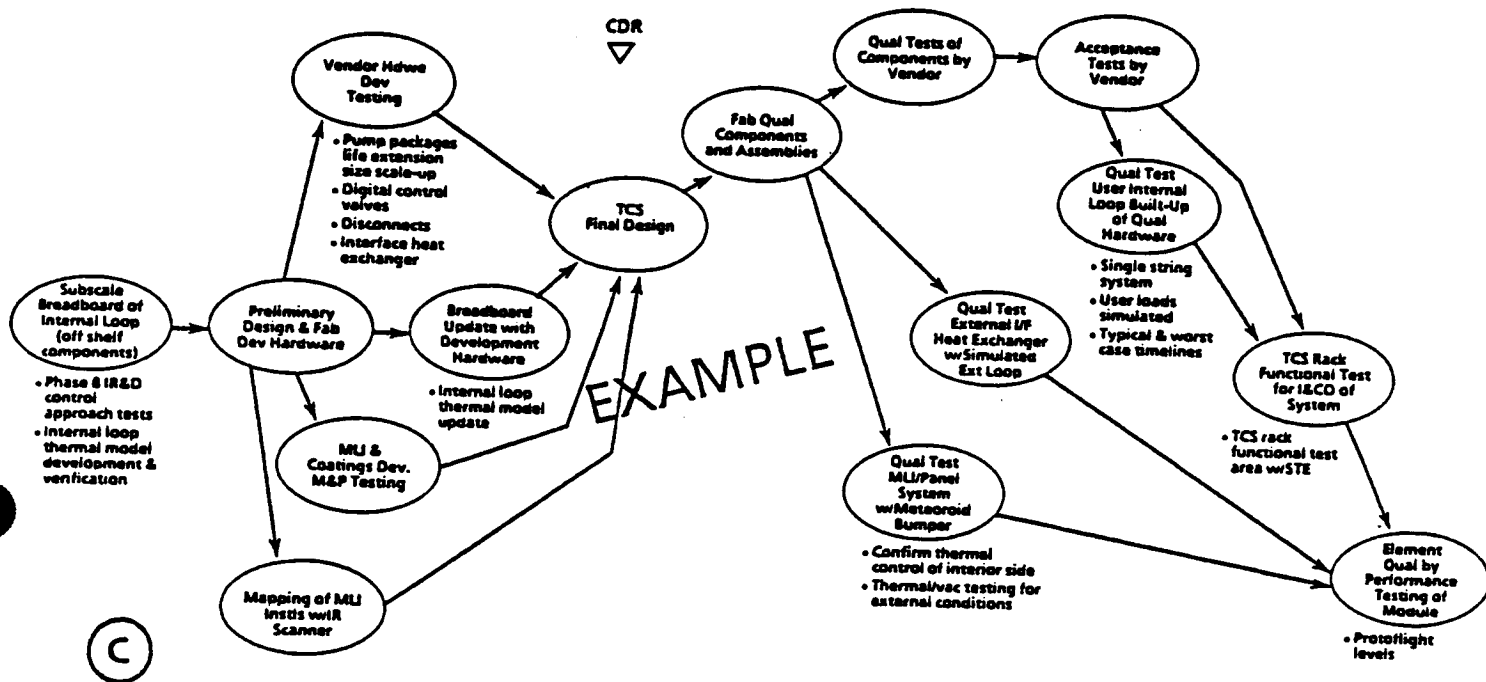


FIGURE 4.2-3 TCS DDT&E FLOW SHEET 2 OF 2

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SHEET 1 OF 11													
ECLSS CERTIFICATION REQUIREMENTS TEMPERATURE & HUMIDITY CONTROL													
TEST	F	P	P	A	R	S	A	T	T	H	E	L	
	U	R	Y	C	A	I	C	H	H	U	M	C	F
	N	E	O	U	N	C	E	E	R	I	D	I	E
	T	S	S	V	V	L	M	M	D	I			
	I	/	S	T	I	B		C	V	T			
	O	L	H	I	B			C	V	T			
	N	E	O	C				Y	A	Y			
LRU / ORU / SUBSYSTEM	A	A	C					C	C				
L	K	K						L					
Temperature and Humidity Control Subsys. (TMC)													
Ventilation Ducting	R	-	-	-	-	-	A	-	-	A	-	A	
Cabin Fan Package	R	R	-	-	R	-	R	-	R	A	R	A	
Condensing Sensible Hx	R	R	-	-	R	-	R	R	-	-	-	A	
Water Separators	R	R	-	-	R	-	R	R	R	A	-	A	
Temperature Controller	R	R	-	-	R	-	R	R	R	A	R	R	
Avionics Fan	R	R	-	-	R	-	R	R	R	R	R	A	
Avionics Sensible Hx	R	R	-	-	R	-	R	R	R	R	R	A	
Valves Manual	R	R	-	-	R	-	R	R	R	R	-	A	
Valve Automatic	R	R	-	-	R	-	R	R	R	R	R	R	
Quick Disconnects	R	R	-	-	R	-	R	R	R	R	-	R	
• Legend R = REQUIRED TEST - = NO REQUIREMENT A = VERIFIED BY ANALYSIS (Includes Similarity)													

SHEET 2 OF 11													
ECLSS CERTIFICATION REQUIREMENTS ATMOSPHERE CONTROL & SUPPLY													
TEST	F	P	P	A	R	S	A	T	T	H	E	L	
	U	R	Y	C	A	I	C	H	H	U	M	C	F
	N	E	O	U	N	C	E	E	R	I	D	I	E
	T	S	S	V	V	L	M	M	D	I			
	I	/	S	T	I	B		C	V	T			
	O	L	H	I	B			C	V	T			
	N	E	O	C				Y	A	Y			
LRU / ORU / SUBSYSTEM	A	A	C					C	C				
L	K	K						L					
Atmosphere Control and Supply Subsystem (ACS)													
O ₂ / N ₂ Pressure Controller	R	R	-	-	R	-	R	R	R	A	R	R	
Low Press. Gas Plumbing	R	-	-	-	-	-	-	-	-	-	-	-	
Positive Relief Valve	A	A	-	-	A	-	A	A	A	A	A	A	
Negative Relief Valve	A	A	-	-	A	-	A	A	A	A	A	A	
Vent Valve	A	A	-	-	A	-	A	A	A	A	A	A	
Equalization Valve	A	A	-	-	A	-	A	A	A	A	A	A	
Quick Disconnects	R	R	-	-	R	-	R	R	R	R	-	R	
Repressuriz. Tanks O ₂ / N ₂	R	R	-	-	R	-	R	R	R	R	-	R	
• Legend R = REQUIRED TEST - = NO REQUIREMENT A = VERIFIED BY ANALYSIS (Includes Similarity)													

(D)

FIGURE 4.2-4 EQUIPMENT TEST REQUIREMENT MATRIX

The element design will provide adequate margins that allow the element to survive, to continue functioning (or to start up and function) and to complete the designated mission even though expected environment levels are exceeded. The environmental test levels for qualification testing will be established based on these design margins, expected mission levels, and the variations in hardware.

Those units selected for Space Station that have been previously qualified and flight proven are not requalified unless the defined mission environment is more severe. All modified hardware requires requalification. The decision process to determine the requirements for qualification testing is shown in Figure 4.3-1. Qualification test requirements for certifying candidate units for flight are met either by conducting tests on identical or similar units, or by analysis based on previous hardware usage.

The qualification status of all WP-01 hardware is displayed in the Verification Data Base which provides the qualification requirements of each hardware item plus its current test level parameters and status, (i.e., previously qualified, flight proven, partially qualified or unqualified).

4.3.1 System Integration Testing

System integration testing is concerned with integration of the subsystems hardware and software over the span of the program. It begins in the development phase with breadboard hardware and is used for design validation with early versions of software so that applications software with an operating system is defined that can be baselined and produced. Typical development issues include system testability investigations, redundancy management investigation, beginning the

development of the human factors data base, packaging investigations, maintenance investigations, etc.

Software development and testing is planned under DR-16. Those tests are expected to be conducted on a computer based SSE, and are assumed to cover verification of software parameters against a computer generated system simulation. Hardware-software compatibility will be verified by conducting tests of the system's operating sequences against a hardware simulation of the system while under software control. This testing would include the automated and commanded test and functional operations of a set of standardized mission sequences. Subsystem test articles will be integrated into the common module configuration in a System Integration Laboratory (SIL) facility.

Objectives of testing in a SIL facility would include:

- a. Demonstrate that signal interfaces are within design margins for signal and noise.
- b. Verify subsystem operating ranges, tolerances and performance under parametric input variations.
- c. Verify component interfaces and compatibility.
- d. Verify inter-subsystem interfaces.
- e. Verify redundancy management capability.
- f. Demonstrate satisfactory operation under identified contingency or failure modes.
- g. Validate power quality and consumption analysis.

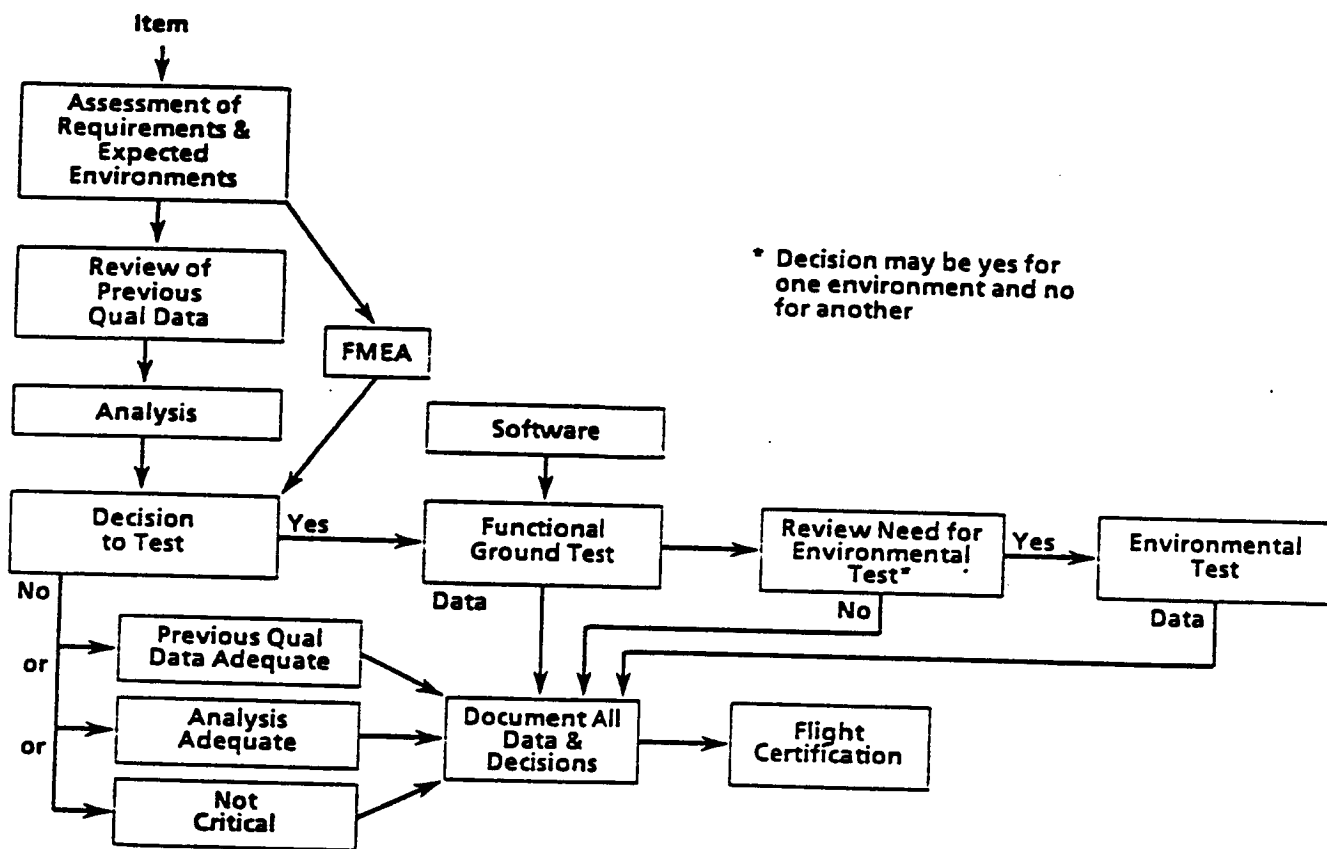


FIGURE 4.3-1 QUALIFICATION TESTING DECISION PROCESS

- h. Verify automatic power down and load management capability.
- i. Verify automatic self-initiation sequences.

From the design and development period, the SIL would transition to support of element checkout, interface verification, outfitting checkout, payload hardware integration, and then support of the operations phase. This transitioning role is shown in Figure 4.3-2. The configuration of the hardware used as test articles in the SIL will also be evolutionary. The systems can largely be built up from hardware resources of the development and qualification test program in lieu of procuring a dedicated set of components and subsystem hardware. Simulations of element interfaces to other elements and the NSTS Orbiter would be needed. Refer to Figure 4.3-3 for SIL configuration evolution phases.

The SIL provides a capability that also supports module functional test and checkout, during both qualification and acceptance. External interfaces with other related areas permit support of training and simulations, payload and experiment integration and verification; and through the mission support complexers, on-orbit support is provided when needed. Figure 4.3-4 depicts the various SIL interfaces. A preliminary projection of requirements for the WP-01 SIL is shown in Table 4.3-I.

4.3.2 Element Protoflight Tests

CEI element level certification testing is conducted on flight elements on a protoflight basis. See the verification flow shown in Appendix B. Static load qualification is performed on the structure. These tests use flight structure with mass simulated components. A static test load to exceed working loads will be applied to

verify load paths through the trunnions for Orbiter installation, and through the berthing interfaces for station installation. Preceding these tests, the pressure shell will be proof tested, and then the leak rate test will be conducted to verify the integrity of the pressure vessels.

Functional tests are performed on the full flight element with live electronics. The vehicle is subjected to a series of functional, leak and mechanical tests. An acoustic test will be conducted to survey internally generated noise.

4.3.2.1 Element Functional Test

The element functional test is a system segment level test of the module to verify that: (1) all functional interfaces are correct; (2) interactions between system (element, interconnects, orbiter, if required, and ground support interfaces) are proper; and (3) element system level performance requirements are met.

The test will consist of using a checkout station and interface simulators to cycle the element systems through their total range of operation including the launch, orbiter pre-deployment, and post-orbiter assembly into the station, activation and operations. All mission functions are exercised in normal mission sequences via commands, data transmission, etc., including verification of housekeeping data, system control functions, user accommodation interfaces, etc. All operating modes are exercised during the test.

The test configuration will be as close to flight as practical, i.e., minimum STE attached and high-fidelity simulators used. Preliminary plans are that the checkout station interfaces with the element through an umbilical interface. The use of "test only" umbilicals is discouraged in keeping with the general philosophy of using flight

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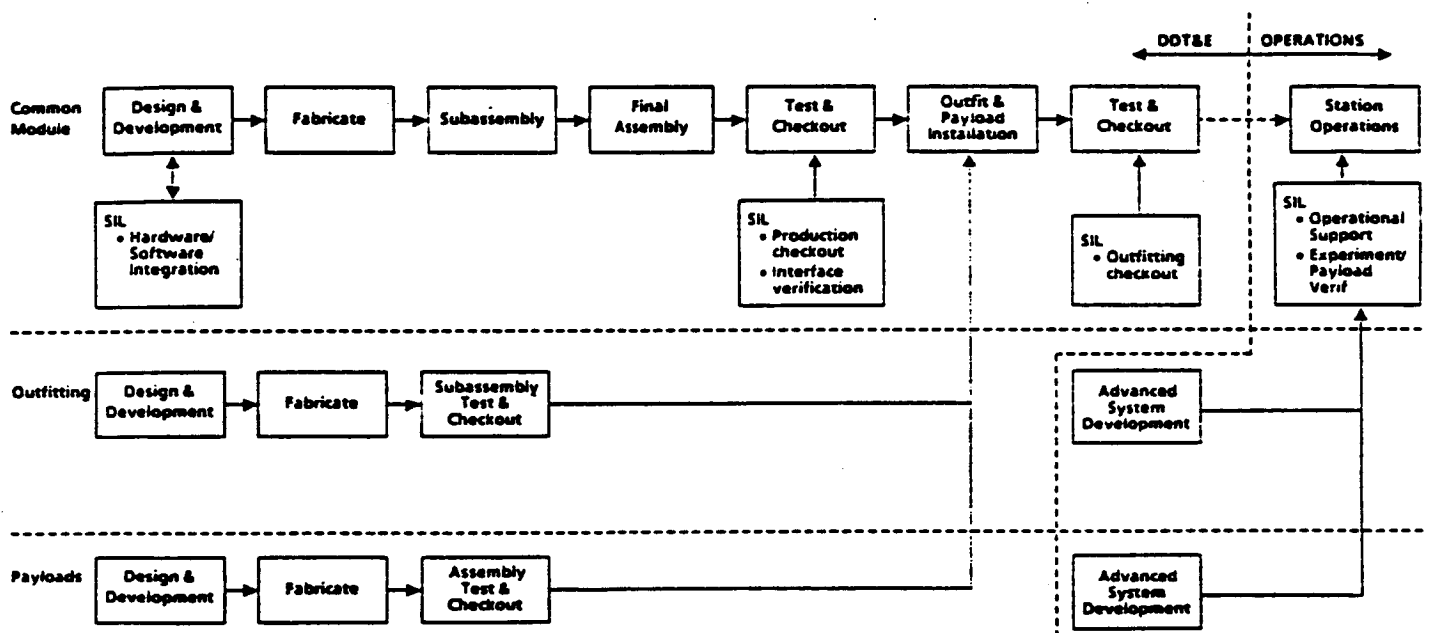


FIGURE 4.3-2 SIL SUPPORT CONCEPT

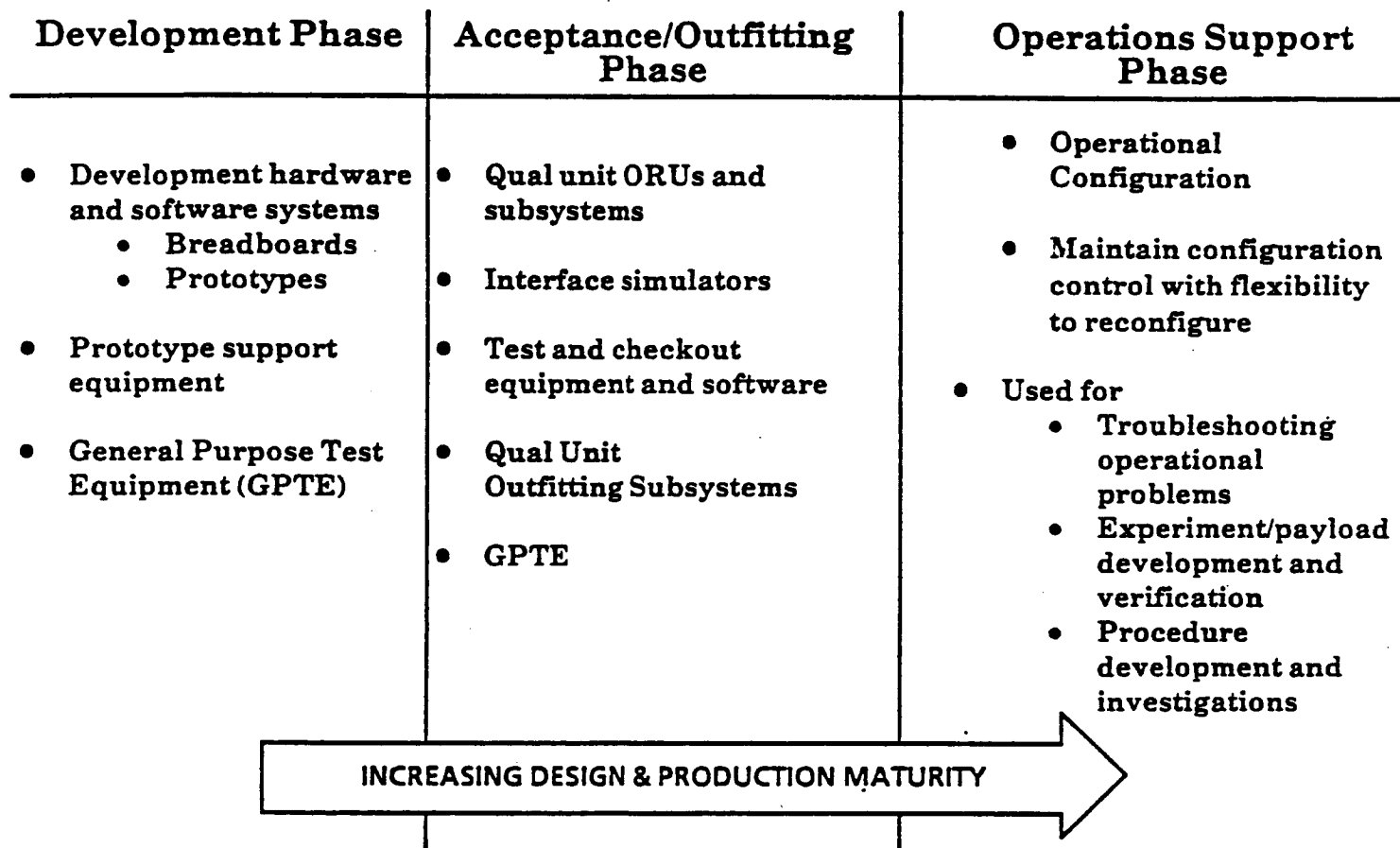


FIGURE 4.3-3 SYSTEMS INTEGRATION LABORATORY CONFIGURATION EVOLUTION

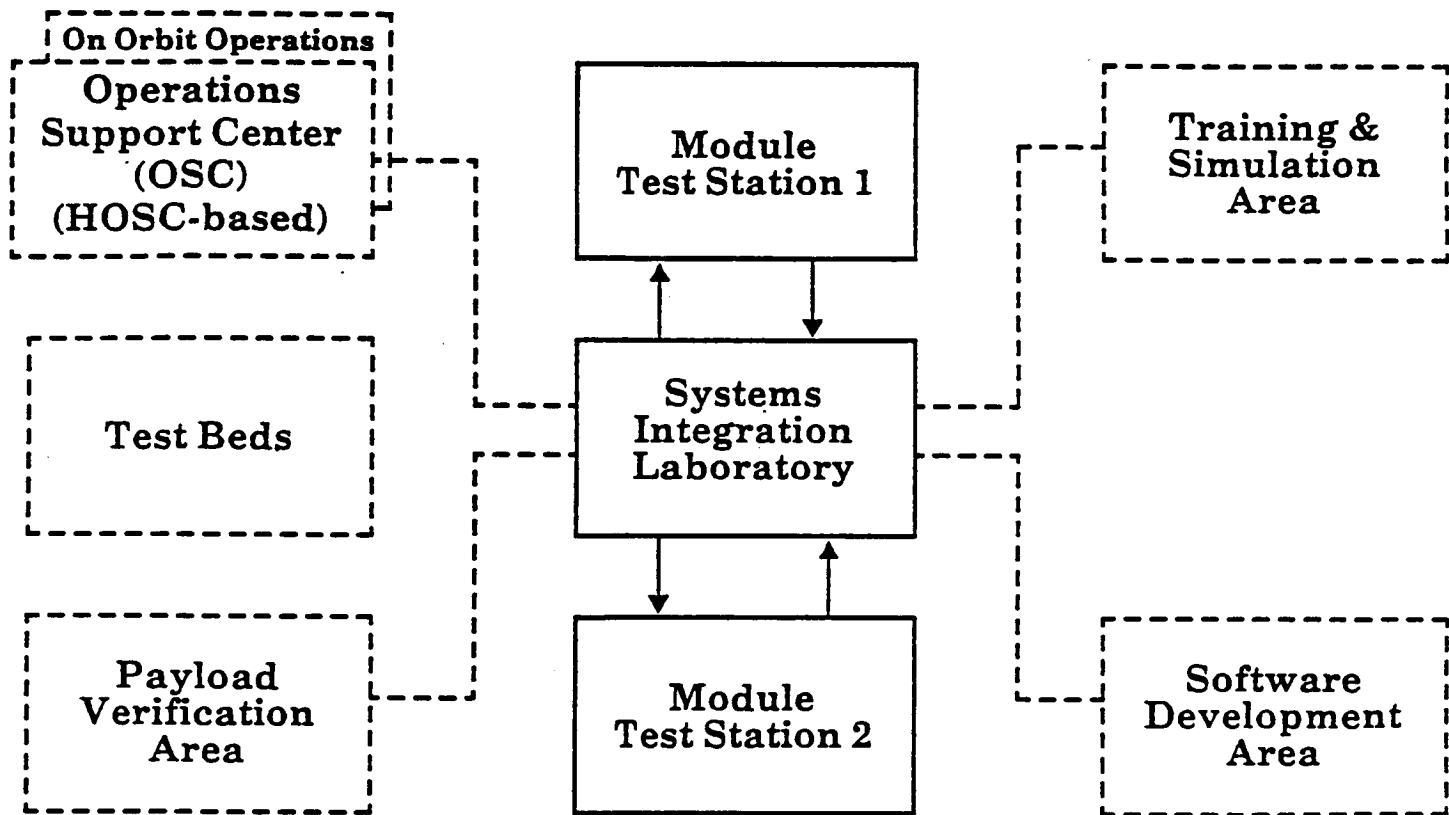


FIGURE 4.3-4 SIL INTERFACES

TABLE 4.3-I PRELIMINARY SIL FACILITY REQUIREMENTS

Mission: Module acceptance test and checkout, plus installation of outfitting equipment and outfitting checkout.*

Facility Requirements:

Two parallel module test stations

7,500 sq ft each

15,000 sf

Module transporter access

Roadway

Doors

24 ft high x 20 ft wide

Overhead bridge crane with 40' hook height

Single hook lift, or

1 @ 30 tons or

Double hook lift

2 @ 20 tons

Contamination control

2 ea class 100,000 clean tents, 80 ft x 65 ft x 30 ft

Computer area for GSE,

Simulators, checkout control station, etc.

3,000 sf

Industrial utilities

Lighting

Power Clean dry compressed gasses

* Area estimates for payload integration, experiment verification & software lab not included

interfaces for tests whenever possible. A payload simulator is to simulate typical user accommodation interfaces that are monitored or commanded through the element including power status and control and data stream functions. Electrical power is to be provided from a ground power supply unit connected through the umbilical.

A functional test is performed to verify the operation of the umbilical mechanism. The umbilicals are physically separated and then manually reconnected. The systems are then functionally checked out in the automatic mode monitored with the checkout station as previously described.

The element system functional test is planned to be performed at key points during protoflight processing (e.g., before and after outfitting and payload integration) and provides, in addition to basic system performance, data indicative of any significant changes in performance which show undesirable trends.

4.3.2.2 Electromagnetic Compatibility (EMC) Test

The EMC certification test uses the combined module systems with outfitting and payload equipment installed. Electromagnetic tests are performed to verify that levels electromagnetic interference between systems and components are acceptable and to ensure that the module element is not adversely affected by external sources of RF radiation. It is to be conducted in accordance with MIL-E-6051D requirements. When element schedule requirements are clear, tests may be combined for more efficient operation when practical.

4.3.3 Qualification Tests

4.3.3.1 General

Planning for environmental qualification tests will generally follow the guidance of MIL-STD-1540A and/or MIL-STD-810. Specific test levels are to be confirmed through developmental testing and by the thermal and dynamic analyses. Qualification test levels will be chosen to exceed the expected flight levels to ensure that environmental exposure of production hardware during the missions are within design margins. These levels will be based on values including the boost phase plus composite values for extended orbital exposure in the environment that the Space Station is to be flown and operated in.

Therefore, simulated space environments during qualification exceed the worst case temperature extremes and include power on, power off, depressurization, repressurization, and restart as required. Simulated launch tests such as vibration, acoustic and acceleration will include the highest dynamic loads from the NSTS orbiter launch environments.

Electronic Orbital Replaceable Units (ORUs) are required to have successfully completed a functional checkout and acceptance test with burn-in prior to being subjected to qualification testing. ORU component level qualification is generally completed prior to start of the protoflight testing at higher levels of assembly.

Vehicle level certification testing on the flight elements is accomplished on a protoflight basis, using flight electronic units, not the ORUs used during component qualification.

If a test failure occurs during qualification, the test is terminated, cause of the failure determined, corrective action completed and the test restart determined. If the cause of failure is due to the test setup or to a failure in the test equipment, the test being conducted at the time of the failure may be continued after the repairs are completed, provided the failure did not result in an overstress test condition. If the cause of the problem is determined as a failure in the unit under test, a preliminary failure analysis and appropriate corrective action is completed and the test restart determined. The qualification test in which the failure occurred, and any previous test that could have induced the failure, or whose validity was compromised by the corrective action, will be repeated. The amount of re-test required after the qualification test failure is determined by a Material Review Board (MRB) consisting of Boeing Engineering, Boeing Quality Control and Customer Quality Control representatives. Success criteria to be applied to all qualification testing is as follows:

1. Equipment must survive or operate (as appropriate) at the environmental extremes without experiencing a failure. Performance parameters must remain within the qualification specification limits although these limits may be wider than those for acceptance testing.
2. No intermittent failures shall occur while the equipment is in, or is being sequenced through, operational modes during environmental exposure. All electrical and electronic equipment is energized and critical circuits are monitored during this sequencing.

3. Complete successful functional tests before and after environmental exposure, with all commands issued and responses verified to assure no performance degradation has occurred during environmental exposure.

4.3.3.2 Certified Hardware List

The end product of certification is the establishment of a certified hardware list. This list of certified items will provide the basis for declaring the design as certified for its intended use. The contractor will complete and submit to MSFC Reliability and Quality Assurance Office a Certificate of Qualification (COQ), MSFC Form 511, for each item that has completed qualification, and when the COQ is approved, will update the certified hardware list. Certification status of all certified Space Station WP-01 flight hardware will be published on the Certified Hardware List and listed in the Certification Status Reports.

Specific qualification test requirements are design-specific and will be contained in the Phase C/D test plans for each of the elements. It should be noted that preliminary planning for the WP-01 flight elements was provided in the preliminary DR-04 submittal dated February 20, 1986. References are as follows:

D483-50023-1, Space Station WP-01 Systems Test and Verification Plan, Volume 1

D483-50023-2, Common Module Systems Test and Verification Plan, Volume 2

D483-50023-3, Manufacturing and Technology Laboratory Module Systems Test and Verification Plan, Volume 3

D483-50023-4, Logistics Module Systems Test and Verification Plan, Volume 4

D483-50023-5, Propulsion and Vehicle Accommodations System Test and Verification Plan, Volume 5

4.4 Hardware Verification

WP-01 element acceptance tests are conducted on production hardware to demonstrate that the designed and manufactured hardware conforms to specification requirements. When the elements are to be subjected to protoflight certification testing, the acceptance testing follows the refurbishment of the element after protoflight testing.

Acceptance tests detect deficiencies in workmanship, material, and quality. An acceptance team of customer and Boeing representatives will review and ensure the overall completeness and acceptability of data acquired before WP-01 equipment is delivered. Control and verification of the acceptance process is an integral part of the quality assurance program.

Production acceptance tests use procedures, facilities, and support equipment produced and verified during the development and qualification tests. When environmental tests are required, they will be conducted at levels commensurate with expected flight levels.

4.4.1 General Acceptance Test Requirements

Environmental acceptance tests are planned using MIL-STD-1540A as guidance. Specific test levels equal expected operating levels. As in the qualification test program, these levels are based on composite values for typical mission conditions for more than one configuration. These missions require extended operations in low earth orbit. Therefore simu-

lated space environments during acceptance exceed the worst case temperature extremes. Simulated launch tests such as vibration, acoustic, and acceleration include the highest dynamic loads anticipated.

If a test failure occurs, the test is terminated, cause of the failure determined, corrective action completed, and the test restart determined. If the cause of failure is due to the test setup or to a failure in the test equipment, the test being conducted at the time of the failure may be continued after the repairs are completed, provided the failure does not result in an overstress test condition. If the cause of the problem is determined as a failure in the unit under test, a preliminary failure analysis and appropriate corrective action are completed and the test restart determined. The test in which the failure occurs, and any previous test that could have induced the failure, or whose validity was compromised by the corrective action, are repeated. The amount of retest required after a test failure will be mutually determined with the procuring agency.

4.4.2 Element Acceptance Tests

Element acceptance test activities and procedures are planned to be validated during certification tests for the Boeing in-plant activities and for the element tests for KSC; followed by initial processing of the elements at KSC. In a typical element flow acceptance-type functional testing (in process) is planned to be performed in progressive stages: after installation and checkout of system racks; after installation and checkout of outfitting system racks; and after installation and interface verification of payload accommodations hardware that is furnished by the customer community for integration into the modules (this is expected to primarily apply to the USL Module).

4.4.3 FSE Acceptance Tests

The ASE acceptance tests are planned to be conducted with the same production FSE which was used for qualification testing, except that the qualification LRUs are replaced with flight LRUs. The tests are FSE only, that is, not in combination with the vehicle. The FSE acceptance tests verify compliance with the requirements of the FSE product fabrication specification.

4.4.4 Subsystem Acceptance Tests

There are no subsystem acceptance tests planned at this time for the WP-01 elements.

4.4.5 Component/ORU Acceptance Tests

Component acceptance testing is conducted using MIL-STD-1540A for guidance by the prime contractor and all subcontractors. Prior to these standard tests, each electrical LRU/ORU is subjected to a power-on screening vibration test in each of six axes. A functional test is required before and after the screening vibration test.

4.4.6 Ground Support Equipment Acceptance Tests

Acceptance tests for all WP-01 element GSE (before its use with airborne equipment) involve continuity, proof load, interface verification and functional operation. Operational integrity is sustained through periodic calibration and inspection. GSE scheduled for KSC undergoes factory acceptance testing prior to delivery and after final installation at KSC.

4.5 Space Station Ground Systems Verification

4.5.1 Ground Support Equipment Verification

Testing will be performed for verification of both electrical and mechanical ground support equipment. The electrical support equipment will be built up, integrated, and tested in the factory testing area. Testing of the software programs for subsystem checkout will be conducted to verify that input signals to the flight hardware are properly displayed and stored, the output commands from these signals are generated, verified, and stored, the peripherals are properly controlled, the post data processing functions operate properly and the ability of the support equipment to generate, accept, and react to input test scenarios.

The transportation container, module dolly, and supporting ground handling equipment will be subjected to a series of transportation and handling tests which will provide verification that ground handling environments are less severe than the corresponding flight environments. These tests will accomplish the following:

- a. Conduct static load qualification tests.
- b. Verify the interface compatibility and operation of the ground handling slings, assembly fixtures, and work stands.

- c. Develop handling and assembly procedures which will provide the basis for handling, servicing, transportation, and assembly procedures for launch site operations.
- d. Subject appropriate hardware simulations in their shipping containers (i.e., modules, racks, etc.), to "over-the-road" transportation tests. These tests will use the same transportation modes as will be used for shipment to launch site and will be instrumented for dynamic environmental measurements.

4.5.2 Launch Readiness Verification

The operations at the launch site which provide for servicing and deservicing of elements and user equipment will also include verification that systems are launch ready. The testing to be done while mated to the STS, prior to launch, will be constrained by limitations and reasonableness of interfaces such as power and fluid supplied and access. Planned launch readiness testing should be minimized to the extent necessary to validate the general health of the element.

4.6 Test Planning and Conduct

Boeing uses an established systematic approach to test planning on major programs. The customer and all organizations within the project participate in the test flow as shown in Figure 4.6-1 This flow also shows where specification require-

ments and test command media enter the test process. The flow is typically implemented through the following steps:

1. Development of a coordinated, approved test plan.
2. Correlations between requirements and tests through a System Specification Verification Traceability Matrix and Element Specification Verification Traceability Matrix deliverable CEI elements (to be a function of the VDB).
3. Documentation of coordination and incremental testing by approved Test Sequence Documents (a top-level procedure).
4. Test procedures prepared by the conducting organization and approved by the Test Readiness Review.
5. Test readiness reviews and post-test analyses, with customer participation.
6. Test operations conducted with close quality assurance and configuration control under an approved Quality Assurance Plan.
7. Follow Closed-Loop test verification logic to ensure requirements and specification compliance.

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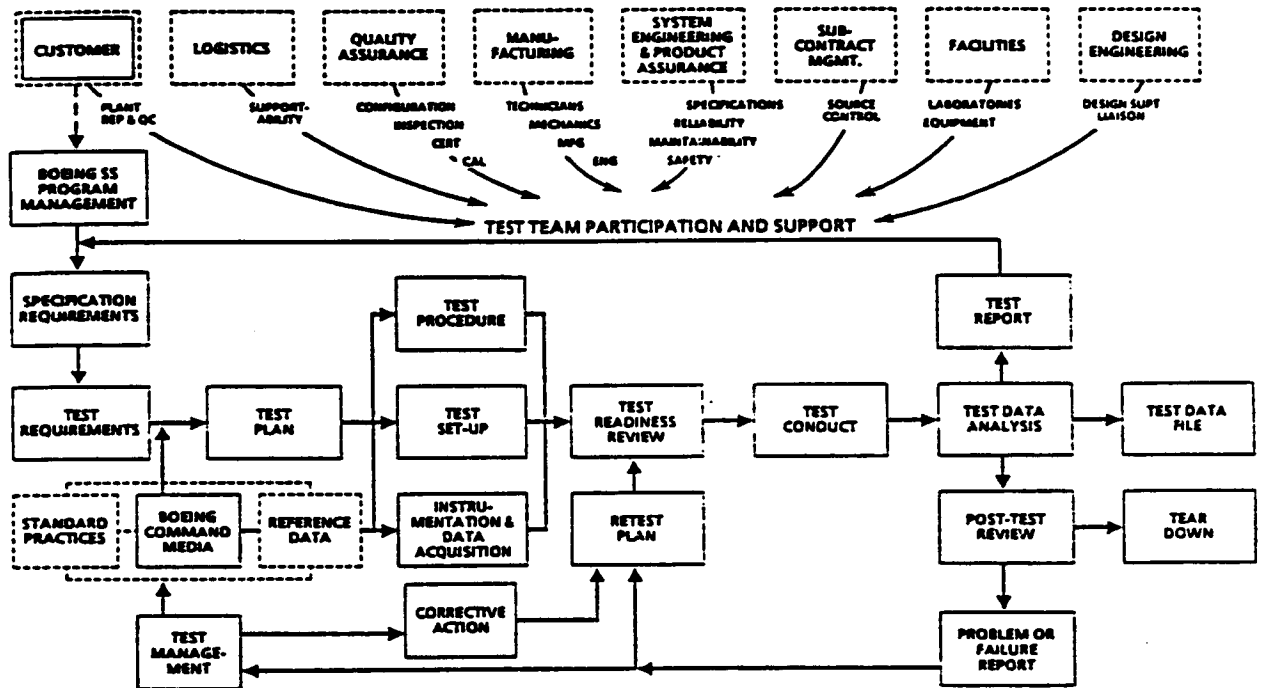


FIGURE 4.6-1 TYPICAL BOEING TEST FLOW

5.0 PRODUCT ASSURANCE

This section summarizes the Safety Analysis and the Failure Mode and Effect Analysis as performed to support the WP-01 SRR Space Station configuration assessment of Elements/Subsystems as identified in SOW.

5.1 Summary of Safety Analysis Findings

The hazardous conditions identified by the Preliminary Hazard Analysis (PHA) as presented in DR-11 are recorded on the worksheets included in this paragraph, and specific suggestions for hazard control are provided therein. As noted earlier, the more lengthy hazard control rationales are simply referenced on the worksheets and provided as separate appendices for the convenience of the reader. Worksheet element/subsystem categories are as follows:

- a. Common Module
- b. ECLSS
- c. Fluid Management
- d. Manufacturing and Technology Laboratory
- e. OMV Accommodations
- f. Operations

The PHA identified 18 different hazardous conditions associated with the Common Module, 10 concerning the ECLSS, and 1 pertaining to OMV Accommodations. For the MTL, a total of 29 hazardous conditions concern the introduction and disposal of hazardous materials needed to conduct experiments. Of the 16 hazardous conditions identified in the Fluid Management PHA, 14 address the same concerns involving Fluid Management functions that were addressed in the Common Module,

MTL, and OMV Accommodations PHAs. One of the concerns unique to Fluid Management is the local contamination of the Space Station's external atmosphere. The other unique Fluid Management concern deals with external leaks of pressure vessels and pipes and their effect on the Station's attitude control system, as does the hazardous condition identified for OMV Accommodations. The WP-01 Operations PHA identified seven generic hazardous conditions associated with WP-01 assembly operations. Thus, the PHAs identified a total of 40 unique hazardous conditions associated with WP-01 elements and systems, plus their interfaces and assembly operations.

The hazardous conditions reported in this document do not reflect any risk assessment; establishment of a qualitative risk determination is premature when applied to the conceptual phase of a design. References to probability of debris impact to the module and the attendant statements or hazard control adequacy are based on NASA published data of the debris flux estimated to be present in 1992. Estimates of module wall and debris protection barrier thicknesses are based on current test; however, the test program is not yet complete. Reference to adequacy of the ionizing protection strategy is based on current knowledge of ionizing radiation effects on humans and NASA radiation exposure limits. These limits are currently being reviewed by NASA.

The hazardous conditions have been assessed to determine whether the hazard control strategy suggested can be implemented within current state-of-the-art technology. For implementing the postulated hazard control strategies, the follow-

TABLE 5.0 WORK PACKAGE RESPONSIBILITY ASSESSMENTS

<u>Element/Subsystem</u>	<u>Work Package Responsible:</u>				
	<u>WP-01</u>	<u>WP-02</u>	<u>WP-03</u>	<u>WP-04</u>	<u>INT.</u>
1. Common Module	X				
2. Manufacturing & Tech. Laboratory	X				
3. Habitation/Station Operations Module		X			
4. Japanese Experiment Module (JEM)					X
5. Experiment Logistics Mod.					X
6. Columbus Lab Module (ESA)					X
7. Logistics Elements	X				
8. Airlocks	X				
9. Interconnects	X				
10. Remote Payload Accom.			X		X
11. OMV Accommodations	X				
12. Servicing Facility			X		
13. MSC		X			X
14. Solar Power Mod.				X	
15. Truss Element		X			
16. Polar Platform			X		X
17. Co-orbiting Platform			X		X
18. Propulsion Element		X			

Overall Architecture Responsibility For Distributed Subsystems:

Electrical Power Sys.				X
Thermal Control System		X		
SSIS		X		
Comm. & Tracking		X		
GN&C		X		
ECLSS	X			
EVAS		X		
Fluid Mgmt.	X			
Man Systems		X		

ing areas require research efforts to be funded by the Space Station Program:

1. Contamination of internal environment.
2. Toxicity.
3. Microbiological growth within module.
4. Airborne microbiological control method.
5. Leak-proof connectors and leak monitors.
6. Metal joining other than riveting in orbit.
7. High expansion ratio nozzles for safe disposal of gaseous wastes in orbit.

As derivatives of these identified technology gaps, certain activities currently funded by NASA require prompt completion. These activities are:

1. Promulgation of the maximum allowable concentration (MAC) specification for long-term Space Station environmental contamination.
2. Development of a test protocol for uniform testing of long-term material outgassing characteristics.
3. Establishment of the allowable external contamination level based on each user-equipment contamination effect.

Some hazardous conditions are identified as being the responsibility of all NASA Centers and international partners. These may best be coordinated by the issuance of Level B standards. Additional analysis information is included in D483-50073-1,

Space Station Preliminary Safety Analysis (DR-11), dated June 23, 1986.

5.2 Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) results provide information for identifying single failure points, formulating redundancy strategies, designing caution and warning systems, defining maintenance requirements, and spares provisioning; and providing confidence on risk acceptance decisions. The FMEA activities during the definition and preliminary design effort supported the SRR Space Station Configuration and were presented in DR-12.

The FMEAs were performed by BAC-Huntsville, and subcontractors during definition and design activities for the manned and man-tended station.

The initial FMEA effort employs a top-down approach to evaluate the criticality of individual functions/subfunctions to safety and mission.

Specifically the FMEAs start with a function and trace the effect of the lack of function; the presence of the function when not required, and the absence of the function when required through the design.

The FMEAs are performed to the subsystem level as defined in the DR-02 Preliminary Analyses and Design Documents. Components and/or subsystems below the subsystem level analyzed are treated as "Black Boxes" that provide and receive data, i.e., input and output data to and out of the "Black Boxes." Mechanical, electro-mechanical, and electric subsystems are considered black boxes. However, the function of the black box is described in sufficient detail so that the reader can understand the operation of the entire system

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT / SYSTEM COMMON MODULE PAGE 1 OF 10

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
1	CONTAMINATION OF INTERNAL ENVIRONMENT	1. MICROBIAL BUILDUP BEYOND HUMAN TOLERANCE. 2. TRACE CONTAMINANTS.	LOSS OF CREW.	1	1. THE MAGNITUDE OF THIS THREAT CANNOT BE ACCURATELY ESTABLISHED AT THIS TIME. FURTHER INVESTIGATION IS REQUIRED. 2. A TRACE CONTAMINANT MONITORING AND PRO-CESSING CONTROL STRATEGY HAS BEEN DEVELOPED; SEE APPENDIX I FOR DETAILS.
2	IONIZING RADIATION	IONIZING RADIATION (WAVELENGTHS OF LESS THAN 300 NANOMETERS) WILL BE PRESENT IN THE SPACE STATION ENVIRONMENT.	CONTINUED EXPOSURE TO IONIZING RADIATION WILL RESULT IN SEVERE ILLNESS OR DEATH OF CREWMEMBER(S).	1	AN "IONIZING PROTECTION STRATEGY" HAS BEEN DEVELOPED FOR THE COMMON MODULE, BASED UPON THE NASA-ALLOWED IONIZING RADIATION DOSE AND THE CREW'S "USEFUL LIFE" OF 20 YEARS. SEE APPENDIX J FOR DETAILS.
3	NON-IONIZING RADIATION	NON-IONIZING RADIATION (WAVELENGTHS OF 300 NANOMETERS OR MORE) WILL BE PRESENT IN THE SPACE STATION ENVIRONMENT.	DETRIMENTAL BEHAVIORIAL CHANGES OF THE CREW MAY RESULT. ALSO, THE CREW WILL EXHIBIT INCREASED BODY TEMPERATURES UPON EXPOSURE TO MICROWAVE RADIATION.	1	THE THREAT OF NON-IONIZING RADIATION WITHIN THE SPACE STATION IS CONTROLLED BY REQUIRING COMPLIANCE WITH MIL-STD-461B, "ELECTROMAGNETIC EMISSION AND SUSCEPTIBILITY REQUIREMENTS FOR THE CONTROL OF ELECTRO-MAGNETIC INTERFERENCE," AND A CONTROL PLAN HAS BEEN DEVELOPED. THE THREAT WHILE OUTSIDE OF THE MODULE DURING EVA MAY BE SIGNIFICANT DUE TO RADIATION FROM THE SPACE STATION ANTENNAS.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM _____ COMMON MODULE _____ PAGE 2 OF 10

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
4	TOXICITY	1. TRACE CONTAMINANTS IN THE AIR, INCLUDING BYPRODUCT OF COMBUSTION. 2. FLUID SPILLS.	SEVERE INJURY OR DEATH OF THE CREW MAY RESULT DUE TO CHEMICAL REACTION WITH HUMAN TISSUE OR DUE TO INTERNAL ORGAN DYSFUNCTION.	1	1. A TRACE CONTAMINANT MONITORING SYSTEM HAS BEEN DEVELOPED TO CONTROL THIS HAZARD; SEE APPENDIX 1 FOR DETAILS. 2. A HAZARDS CONTROL METHODOLOGY FOR CHEMICALS (FLUIDS AND GASES) HAS BEEN DEVELOPED; SEE APPENDICES K-M FOR DETAILS.
5	ELECTRICAL SHOCK	CREWMEMBER CONTACT WITH ELECTRICALLY ENERGIZED CIRCUIT.	DEPENDING UPON THE MAGNITUDE AND DURATION OF EXPOSURE, CREWMEMBER WILL EXPERIENCE REACTIONS RANGING FROM MINOR DISCOMFORT TO DEATH.	1	THE HAZARD CONTROL STRATEGY FOR THIS ITEM IS TO AVOID DIRECT HUMAN CONTACT WITH ELECTRICALLY ENERGIZED CIRCUITS. TO CARRY OUT THIS STRATEGY, THE REQUIREMENT HAS BEEN ESTABLISHED THAT A MECHANICALLY-ACTIVATED INTERLOCK BE PROVIDED AT EACH DISCONNECT POINT SO THAT CONNECTION AND DISCONNECTION OF ELECTRICAL CIRCUITS CAN BE ACCOMPLISHED WITHOUT AN ELECTRICAL LOAD ON THE CIRCUITS.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 3 OF 10

ELEMENT /SYSTEM COMMON MODULE

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
6	ELECTRICAL ARCING	<ol style="list-style-type: none"> 1. BROKEN INSULATION. 2. CORONA EFFECT. 3. LOAD SWITCHING. 4. ELECTRICAL POWER DISCONNECTION/ CONNECTION DURING MAINTENANCE. 	<p>ARCING WILL PROVIDE AN IGNITION SOURCE FOR NEARBY COMBUSTIBLES. ELECTROCUTION OR BURNS OF THE CREW MAY ALSO RESULT.</p>	1	<ol style="list-style-type: none"> 1. DOUBLY-INSULATED RIBBON CABLE MUST BE USED FOR ALL WIRING OF EQUIPMENT WHICH IS OPERATED IN A STANDARD PRESSURE ENVIRONMENT. 2. FOR THE WIRING OF ALL EQUIPMENT OPERATIONS IN ENVIRONMENTS BELOW 2 PSIA, THE MAXIMUM ALLOWABLE VOLTAGES MUST BE 208 VAC AND 250 VDC. 3. BOEING IS CONDUCTING A RESEARCH AND DEVELOPMENT PROGRAM TO DEVELOP NON-ARCING SWITCH MECHANISMS. 4. THE REQUIREMENT HAS BEEN ESTABLISHED THAT A MECHANICALLY-ACTIVATED INTERLOCK BE PROVIDED AT EACH DISCONNECT POINT SO THAT CONNECTION AND DISCONNECTION OF ELECTRICAL CIRCUITS CAN BE ACCOMPLISHED WITHOUT AN ELECTRICAL LOAD ON THE CIRCUIT.
7	EXCESSIVE TEMPERATURE CAUSED BY ELECTRICAL CIRCUITS	<ol style="list-style-type: none"> 1. HIGH-TEMPERATURE SURFACES NOT INSULATED. 2. SHORT CIRCUIT TO GROUND OF ELECTRICAL POWER SOURCE. 	<p>CREWMEMBER MAY BE BURNED UPON CONTACT WITH HOT SURFACE. ALSO, AN IGNITION SOURCE IS PROVIDED FOR NEARBY MATERIALS.</p>	1	<ol style="list-style-type: none"> 1. DURING DETAILED SYSTEM DESIGN, THE INSULATION REQUIREMENTS FOR EACH ITEM MUST BE INVESTIGATED ON A CASE-BY-CASE BASIS. 2. HAZARD CONTROL IS ACCOMPLISHED VIA THE REQUIREMENTS OF END ITEM DATA BOOK D483-50022-2, PARAGRAPHS 3.2.2.4-.10.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM COMMON MODULE PAGE 4 OF 10

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
8	EXCESSIVE NOISE	1. MOVING MECHANISMS. 2. FLUID MOVEMENT IN PIPING AND DUCTING.	ANNOYANCE, LOSS OF HEARING, AND/OR DECREASED PERFORMANCE OF CREWMEMBERS. EVENTUALLY, EVACUATION OF SPACE STATION MAY BE REQUIRED.	1	THIS THREAT MUST BE FURTHER EVALUATED, USING MOCKUPS OF THE SPACE STATION, AFTER THE DESIGN IS MORE FINALIZED.
9	VIBRATION EFFECTS ON HUMANS	SAME AS ITEM 8.	VIBRATIONS WITH FREQUENCIES BETWEEN 1 Hz AND 30 Hz WITH 0.5 g ACCELERATION CAUSE INTERNAL ORGAN DYSFUNCTION OF HUMANS.	1	VIBRATIONS BELOW 30 Hz MUST BE DECOUPLED FROM THE MODULE.
10	LOSS OF STRUCTURAL INTEGRITY	1. CORROSION DUE TO ATOMIC OXYGEN, ULTRA-VIOLET LIGHT, OUT-GASSED MATERIALS, ● PROPULSION SYSTEM BYPRODUCTS, OR PROPELLANT LEAKS. 2. VIBRATION. 3. FATIGUE. 4. DEFECT. 5. OVERSTRESS. 6. COLLISION WITH FOREIGN OBJECT. 7. MODULE UNDERPRESSURE (SEE ITEM 12 OF COMMON MODULE PHA).	LOSS OF MODULE, INCLUDING LOSS OF THE CREW IF MODULE IS OCCUPIED AT TIME OF STRUCTURAL FAILURE.	1	DESIGN REQUIREMENTS WHICH CONTROL THIS HAZARD FOR WP-01 ARE GIVEN IN THE END ITEM DATA BOOKS D483-50022-1 THROUGH -6, SUBMITTED UNDER DR-02. THIS CONCERN MUST ALSO BE ADDRESSED BY THE OTHER WP'S.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 5 OF 10

ELEMENT/SYSTEM COMMON MODULE

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
11	LOSS OF ATTITUDE CONTROL	<ol style="list-style-type: none"> 1. LOSS OF ELECTRICAL POWER TO CMG'S AND PROPULSION SYSTEM. 2. IMPULSE GREATER THAN PROPULSION CAPABILITIES. 3. CONSTANT PROPULSION. 4. LOSS OF CMG'S. 	UNCONTROLLED ROTATION ABOUT AN UNIDENTIFIABLE AXIS. EVENTUAL LOSS OF SPACE STATION.	1	<ol style="list-style-type: none"> 1. THIS THREAT MUST BE EVALUATED BY WP-02. 2. THE TOTAL IMPULSE PROVIDED BY DECOMPRESSION OF A 5,783 FT3 MODULE IS 3.842×10^5 N-SEC. ALLOWANCE FOR THIS IMPULSE MUST BE CONSIDERED BY WP-02. 3. THE HAZARD CONTROL STRATEGY FOR THIS THREAT IS TO REQUIRE THAT THE PROPULSION SYSTEM MUST HAVE AT LEAST TWO SERIALLY-LOCATED, INDEPENDENTLY OPERATED SHUT-OFF VALVES. IN ADDITION, IT MUST BE REQUIRED THAT ALL ATMOSPHERIC VENTING BE ACCOMPLISHED IN A NON-PROPULSIVE MANNER. THIS STRATEGY, FURTHER DESCRIBED IN APPENDIX K, WAS DEVELOPED WHILE IT WAS A WP-01 RESPONSIBILITY. HOWEVER, THIS IS NOW THE RESPONSIBILITY OF WP-02. 4. THE PROPULSION SYSTEM MUST BE CAPABLE OF PROVIDING ATTITUDE CONTROL, IN ADDITION TO REBOOST, IN ORDER TO PROVIDE A BACKUP FOR THE CMG'S. (THIS IS A WP-02 RESPONSIBILITY.)

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM COMMON MODULE PAGE 6 OF 10

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
12	MODULE UNDERPRESSURE	<ol style="list-style-type: none"> 1. METEORITE/DEBRIS PENETRATION. 2. EXPLOSION WITHIN THE MODULE. 3. PENETRATION CAUSED BY SHORT TO GROUND OF ELECTRICAL POWER SOURCE. 4. BROKEN SEAL. 5. CORROSION. 6. LOSS OF STRUCTURAL INTEGRITY (SEE ITEM 10 OF COMMON MODULE PHA). 	<p>RAPID DECOMPRESSION OF MODULE MAY RESULT, RENDERING THE SPACE STATION UNINHABITABLE, DEPENDING UPON THE SIZE OF THE PENETRATION. ALSO, LOSS OF CREW MAY RESULT IF CREW EVACUATION FROM THE MODULE CANNOT BE ACCOMPLISHED WITHIN 150 SECONDS. IF THE PENETRATION IS EXCESSIVELY LARGE, IT MAY BECOME NECESSARY TO ABANDON ONE OR MORE CREWMEMBERS IN THE DAMAGED MODULE TO PRECLUDE LOSS OF THE REMAINING CREWMEMBERS AND THE SPACE STATION.</p>	1	<ol style="list-style-type: none"> 1. A CONTROL STRATEGY FOR THIS THREAT HAS BEEN DEVELOPED; SEE APPENDIX N FOR DETAILS. 2. CONTROL STRATEGIES HAVE BEEN DEVELOPED FOR DEALING WITH THIS THREAT; SEE APPENDICES K THROUGH M. 3. HAZARD CONTROL IS ACCOMPLISHED VIA THE REQUIREMENTS OF END ITEM DATA BOOK D483-50022-2, PARAGRAPHS 3.2.2.4-.10. 4. REQUIRE THAT ALL SEALS OF UTILITY PENETRATIONS TO MODULES BE TWO-FAULT TOLERANT. 5. CONTROL STRATEGIES HAVE BEEN DEVELOPED FOR INTERNAL CORROSION; SEE APPENDICES K THROUGH M. STUDIES ARE BEING CONDUCTED TO DETERMINE THE DETRIMENTAL EFFECTS OF ATOMIC OXYGEN. <p>NOTE: THESE THREATS CREATE THE NEED TO DETECT AND LOCATE THE SOURCE OF THE LEAK REMOTELY, ADVISE THE CREW OF IMPENDING DANGER AND IMPLEMENT THE PROPER CORRECTIVE ACTION. RESEARCH ON THE SELECTION OF APPROPRIATE DETECTION DEVICES IS BEING CONDUCTED BY BOEING. IN ADDITION, BOEING HAS A RESEARCH PROGRAM UNDERWAY TO DESIGN A CREW-ACTIVATED, AUTOMATIC HATCH WHICH CLOSSES WITHIN 10 SECONDS.</p>

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 7 OF 10

ELEMENT / SYSTEM		COMMON MODULE			
ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
13	MODULE OVERPRESSURE	ECLSS FAILURE (SEE ECLSS PHA ITEMS 1, 3 & 4.	MODULE ATMOSPHERE SET POINT WILL BE HIGHER THAN NORMAL, LEADING TO INJURY OR DEATH OF THE CREW. SEVERE OVERPRESSURE WILL RESULT IN MODULE RUPTURE.	I	SEE ECLSS PHA ITEMS 1, 3 & 4.
14	MATERIAL INCOMPATIBILITIES	INHERENT CHARACTERISTICS OF MATERIALS.	EXPLOSION, FIRE, HIGH PRESSURE, LOW PRESSURE, HIGH TEMPERATURE, LOW TEMPERATURE, LEAKS, OR CORROSION OF ADJACENT MATERIALS. CREW IMPAIRMENT OR DEATH MAY ALSO RESULT.	I	CONTROL STRATEGIES INCLUDE EQUIPMENT ZONING WITHIN THE MODULES, SEPARATION OF INCOMPATIBLE AND REACTIVE FLUIDS INTO INDEPENDENT PIPE RUNS, ISOLATION CAPABILITIES TO CONTAIN LEAKS AND SPILLS, AND CASE-BY-CASE ANALYSIS OF THE PRESSURE, REACTIVITY AND OTHER CHARACTERISTICS OF EACH FLUID.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM COMMON MODULE

15

HAZARDOUS CONDITION

ITEM

CAUSE

EFFECT

HAZARD CATEGORY

HAZARD CONTROL

15

IGNITION OF COMBUSTIBLE MATERIALS WITHIN MODULE

PRESENCE OF IGNITION SOURCE, COMBUSTIBLE MATERIALS AND OXIDIZER WITHIN MODULE IN PROPER PROPORTIONS SO AS TO PRODUCE AN EXOTHERMIC REACTION.

FIRE (HAVING MINIMUM TO CATASTROPHIC RESULTS, DEPENDING UPON THE FACTORS INVOLVED). CREW INCAPACITATION OR DEATH MAY RESULT DUE TO BURNS AND/OR TOXIC BYPRODUCTS OF THE COMBUSTION OF MODULE MATERIALS.

1

THE HAZARD CONTROL STRATEGY IS TO CONTROL THE MATERIALS ALLOWED IN THE SPACE STATION AND CONTROL IGNITION SOURCES. ZONING OF FLUIDS AND FLUID MANAGEMENT OF UTILITIES' CONNECTIONS ARE PART OF THE ACTION TO BE TAKEN TO PREVENT IGNITION SOURCES CAUSED BY FLUIDS' CHEMICAL REACTIONS AND FLUID INTERACTION WITH ELECTRICAL CIRCUITS. OTHER CONTROLS INCLUDE THE INCORPORATION OF SPECIAL FEATURES IN THE DESIGN SUCH AS DEAD-FACE CONNECTIONS, INSULATING MATERIALS, AND SHORT-CIRCUIT PROTECTION. COUNTERMEASURES TO BE PROVIDED INCLUDE INFRARED FIRE DETECTION WITHIN THE MODULE'S CENTER AISLE, FIRE DETECTION WITHIN AVIONICS EQUIPMENT RACKS AND A TRACE CONTAMINANT MONITORING AND PROCESSING CONTROL STRATEGY (SEE APPENDIX I FOR DETAILS OF THE LATTER). THE INFRARED FIRE DETECTION FUNCTION MUST BE DESIGNED TO BE TWO-FAULT TOLERANT WITHIN EACH MODULE. FIRE DETECTION WITHIN THE AVIONICS EQUIPMENT RACKS MUST CONSIST OF A THREE-FAULT TOLERANT SMOKE DETECTION SYSTEM WITHIN THE AIR RETURN DUCTS, BACKED UP BY A ZERO-FAULT TOLERANT TEMPERATURE RISE DETECTION SYSTEM WITHIN EACH RACK. THESE FIRE DETECTION AND TRACE CONTAMINANT SYSTEMS ARE MANDATORY FROM A SAFETY VIEWPOINT.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 9 OF 10

ELEMENT/SYSTEM COMMON MODULE

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
16	LOSS OF COOLANT IN THERMAL CONTROL SYSTEM	1. PUMP FAILURE. 2. PUMP CONTROL FAILURE. 3. PIPE BREAKAGE. (FOR SPECIFIC CAUSES OF FAILURE, SEE DR-12 FMEA.)	CREW ASPHYXIATION DUE TO LOSS OF CO2 REDUCTION CAPABILITY. LOSS OF AVIONICS WILL ALSO RESULT, POSSIBLY CAUSING LOSS OF SPACE STATION.	1	THE PUMP AND PIPING OF THE THERMAL CONTROL SYSTEM MUST BE TWO-FAULT TOLERANT. THE COOLING SYSTEMS FOR CRITICAL AVIONICS SYSTEMS (AS DEFINED BY WP-02) MUST ALSO BE TWO-FAULT TOLERANT. THE PUMP CONTROLLER SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.
17	LOSS OF ELECTRICAL POWER TO SAFETY-CRITICAL SYSTEMS	FAILURE OF MODULE ELECTRICAL POWER DISTRIBUTION SYSTEM. (FOR SPECIFIC CAUSES OF FAILURE, SEE DR-12 FMEA.)	LOSS OF CREW AND/OR SPACE STATION HABITABILITY, DEPENDING UPON THE SPECIFIC SYSTEM WHICH LOSES POWER.	1	ELECTRICAL POWER DISTRIBUTION WITHIN THE SPACE STATION MUST BE TWO-FAULT TOLERANT. GENERATION AND DISTRIBUTION OF ELECTRICAL POWER TO THE MODULE IS THE RESPONSIBILITY OF WP-04. THE SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 10 OF 10

ELEMENT/SYSTEM COMMON MODULE

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
16	INABILITY OF DMS TO COMMAND SAFETY-CRITICAL SYSTEMS	FAILURE OF DMS HARDWARE. (FOR SPECIFIC CAUSES OF FAILURE, SEE DR-12 FMEA.)	LOSS OF CREW AND/OR SPACE STATION HABITABILITY, DEPENDING UPON THE SPECIFIC SYSTEM FOR WHICH COMMAND CAPABILITY IS LOST.	1	TRIPLE REDUNDANCY USING THE STANDBY-AND-POWERED OPTION MUST BE USED FOR THE DMS INTERNAL MODULES. IN ADDITION, SOME SYSTEMS MAY REQUIRE AUTOMATIC LOCAL CONTROL. THE SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 1 OF 5

ELEMENT/SYSTEM ECLSS

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
1	LOSS OF MODULE VENTING CAPABILITY	1. FAILURE OF VENT VALVE IN CLOSED POSITION. 2. LOSS OF VENT VALVE CONTROL SIGNAL. 3. MISHANDLING OR ABUSE OF VENT VALVE.	MODULE ATMOSPHERE SET POINT WILL BE HIGHER THAN NORMAL, LEADING TO INJURY OR DEATH OF THE CREW. SEVERE OVER-PRESSURE WILL RESULT IN MODULE RUPTURE.	1	REDUNDANT INSTALLATION OF VENT VALVES WITH MANUAL OVERRIDES TO EITHER CLOSE OR OPEN THE VALVES. THE VALVE CONTROLLER SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.
2	UNCONTROLLED VENTING OF MODULE	1. FAILURE OF VENT VALVE IN OPEN OR PARTIALLY-OPEN POSITION. 2. IMPROPER VENT VALVE CONTROL SIGNAL. 3. MISHANDLING OR ABUSE OF VENT VALVE.	MODULE ATMOSPHERE SET POINT WILL BE LOWER THAN NORMAL, POSSIBLY LEADING TO INJURY OR DEATH OF THE CREW. SEVERE DEPRESSURIZATION WILL RESULT IN LOSS OF MODULE HABITABILITY.	1	SAME AS ITEM 1.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 2 OF 5

ELEMENT/SYSTEM ECLSS

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
3	OXYGEN ENRICHMENT OF MODULE ATMOSPHERE	<ol style="list-style-type: none"> 1. FAILURE OF N2 FLOW CONTROL VALVE IN THE CLOSED POSITION. 2. LOSS OF N2 VALVE CONTROL SIGNAL. 3. FAILURE OF O2 FLOW CONTROL VALVE IN THE OPEN OR PARTIALLY-OPEN POSITION. 4. IMPROPER O2 VALVE CONTROL SIGNAL. 5. MISHANDLING OR ABUSE OF FLOW CONTROL VALVE. 6. DEPLETION OF N2 RESERVE. 	POSSIBLE HYPEROXIA OF THE CREW AND INCREASED POSSIBILITY OF FIRE WITHIN THE MODULE. OVERPRESSURIZATION OF THE MODULE MAY ALSO RESULT.	1	<p>REDUNDANT NITROGEN SUPPLY VALVES AND CONTROL LOOPS MUST BE PROVIDED.</p> <p>SERIALY-CONNECTED OXYGEN SUPPLY VALVES MUST BE PROVIDED WITH MANUAL OVERRIDE.</p> <p>LOGISTIC SUPPLY OF NITROGEN MUST BE PROVIDED ON A 45-DAY CYCLE.</p> <p>THE VALVE CONTROLLER SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.</p>

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM ECLSS

PAGE 3 OF 5

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
4	OXYGEN DEPLETION OF MODULE ATMOSPHERE	<p>1. FAILURE OF N2 FLOW CONTROL VALVE OR CO2, N2 OR INERT GAS RELIEF VALVE IN THE OPEN OR PARTIALLY-OPEN POSITION.</p> <p>2. FAILURE OF O2 FLOW CONTROL VALVE IN THE CLOSED POSITION.</p> <p>3. IMPROPER CONTROL SIGNAL ISSUED TO N2 OR O2 FLOW CONTROL VALVE OR TO CO2, N2 OR INERT GAS RELIEF VALVE.</p> <p>4. MISHANDLING OR ABUSE OF VALVE.</p> <p>5. DEPLETION OF O2 RESERVE.</p>	POSSIBLE ASPHYXIATION OF THE CREW. OVERPRESSURIZATION OF THE MODULE MAY ALSO RESULT.	1	<p>SERIALY-CONNECTED NITROGEN SUPPLY VALVES MUST BE PROVIDED WITH MANUAL OVERRIDE.</p> <p>REDUNDANT OXYGEN SUPPLY VALVES AND CONTROL LOOPS MUST BE PROVIDED.</p> <p>SERIALY-CONNECTED RELIEF VALVES MUST BE PROVIDED WITH MANUAL OVERRIDE AND REDUNDANT CONTROL LOOPS.</p> <p>OXYGEN MUST BE GENERATED IN ORBIT BY THE WATER ELECTROLYSIS SYSTEMS, IF BASELINED.</p> <p>THE VALVE CONTROLLER SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.</p>

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT / SYSTEM ECLSS

PAGE 4 OF 5

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
5	UNDETECTED TOXIC CONTAMINANTS IN MODULE ATMOSPHERE	FAILURE OF TRACE CONTAMINANT MONITOR. (FOR SPECIFIC CAUSES OF FAILURE, SEE DR-12 FMEA.)	CREW INCAPACITATION OR DEATH. ALSO, THE MODULE MAY BE RENDERED UNINHABITABLE.	1	REDUNDANT TRACE CONTAMINANT MONITORS AND CREW CAUTION AND WARNING NOTIFICATIONS MUST BE PROVIDED. THE BOEING APPROACH TO CONTROL THIS THREAT IS FURTHER DESCRIBED IN APPENDIX I. THE SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.
6	TOXIC CONTAMINANTS NOT REMOVED FROM MODULE ATMOSPHERE	FAILURE OF TRACE CONTAMINANT REMOVAL PROCESS. (FOR SPECIFIC CAUSES OF FAILURE, SEE DR-12 FMEA.)	ACCUMULATION OF CONTAMINANTS IN THE SPACE STATION, POSSIBLY CAUSING INCAPACITATION OR DEATH OF THE CREW.	1	REDUNDANT HIGH TEMPERATURE OXIDIZERS MUST BE PROVIDED. (ALTHOUGH FAILURE OF AN OXIDIZER IN A HIGH-TEMPERATURE MODE WILL INTRODUCE A FIRE HAZARD, THIS MUST BE CONTROLLED BY ISOLATION, ZONING AND BARRIERS.) THE SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.
7	UNDETECTED MICRO-BIOLOGICAL GROWTH WITHIN MODULE	FAILURE OF THE BIOLOGICAL MONITORING SYSTEM.	ILLNESS OR DEATH OF CREW. (MANIFESTATION OF ILLNESS COULD BE SHORT-TERM OR LONG-TERM.)	1	THE BIOLOGICAL MONITORING SYSTEM HAS YET TO BE DEFINED. THE SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT / SYSTEM ECLSS

PAGE 5 OF 5

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
8	AIRBORNE MICRO-BIOLOGICAL AGENTS NOT ELIMINATED	1. LOSS OF ULTRAVIOLET LIGHT SOURCE. 2. AGENTS IMMUNE TO ULTRAVIOLET LIGHT, OR DEVELOP IMMUNITY VIA MUTATION.	SAME AS ITEM 7.	I	1. REDUNDANT ULTRAVIOLET SOURCES MUST BE LOCATED IN THE AIR RETURN DUCTS. (ALTHOUGH THE SOURCES CONTAIN MERCURY, WHICH CAN INTRODUCE A CONTAMINATION HAZARD, THE MERCURY BULBS CAN BE ENCLOSED IN HERMETICALLY-SEALED, EXPLOSION-PROOF COVERS.) 2. TYPES OF MICROBIOLOGICAL AGENTS WHICH CAN LIVE IN THE SPACE STATION ENVIRONMENT ARE UNKNOWN, AS IS THE EFFECTIVENESS OF ULTRAVIOLET LIGHT IN DEALING WITH THEM.
9	HYDROGEN ENRICHMENT OF MODULE ATMOSPHERE	1. FAILURE OF H2 RELIEF VALVE IN THE OPEN POSITION. 2. IMPROPER CONTROL SIGNAL ISSUED TO VALVE.	EXPLOSION MAY OCCUR WITHIN AN EQUIPMENT RACK OR MAY BE DISTRIBUTED THROUGHOUT THE ENTIRE MODULE. THIS WILL OCCUR IF 4% OR MORE OF THE AVAILABLE VOLUME IS COMPOSED OF H2 AND 0.1 MILLIJOULES OF ENERGY IS RELEASED TO TRIGGER THE EXPLOSION. LOSS OF THE CREW AND LOSS OF SPACE STATION HABITABILITY WILL RESULT.	I	SERIALY-CONNECTED, TWO-FAULT-TOLERANT RELIEF VALVES MUST BE PROVIDED WITH MANUAL OVERRIDE AND REDUNDANT CONTROL LOOPS. THE VALVE CONTROLLER SOFTWARE DESIGN SHOULD REFLECT THE SAFETY CONSIDERATIONS PROVIDED IN APPENDIX O.
10	MODULE HUMIDITY BEYOND CO2 REDUCTION SYSTEM TOLERANCE	REDUCED EFFICIENCY OF DEHUMIDIFIER.	RAPID LOSS OF CO2 REMOVAL CAPABILITY IF HUMIDITY CONTROL IS NOT REGAINED. CREW ASPHYXIATION WILL RESULT.	I	THE HUMIDITY CONTROL SYSTEM MUST BE TWO-FAULT TOLERANT. THE COOLING COILS MUST ALSO BE TWO-FAULT TOLERANT.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM FLUID MANAGEMENT			PAGE 2 OF 3	
ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY
8-14	THESE HAZARDOUS CONDITIONS ARE THE SAME AS THOSE IDENTIFIED IN THE MTL PHA AS ITEMS 4, 8, 9, 10, 14, 15 AND 29.	SEE MTL PHA ITEMS 4, 8, 9, 10, 14, 15 AND 29.	SEE MTL PHA ITEMS 4, 8, 9, 10, 14, 15 AND 29.	1
15	LOCAL CONTAMINATION OF SPACE STATION EXTERNAL ATMOSPHERE	1. PRESSURE VESSEL OR PIPING LEAKAGE. 2. PRESSURE VESSEL OR PIPING RUPTURE.	CORROSION OF SPACE STATION STRUCTURE AND/OR OTHER EXPOSED MATERIALS. LOSS OF SPACE STATION HABITABILITY MAY RESULT. IF RUPTURE OCCURS, DEBRIS DAMAGE TO SPACE STATION STRUCTURE AND EQUIPMENT MAY RENDER IT UNINHABITABLE.	1
			HAZARD CONTROL	
			<p>SAME AS ITEMS 1-6.</p> <p>ALL PRESSURE VESSELS MUST BE DESIGNED TO LEAK BEFORE RUPTURING.</p> <p>PRESSURE VESSEL VENTING DEVICES MUST BE LOCATED SO AS TO PREVENT DAMAGE TO ADJACENT EQUIPMENT.</p> <p>ADEQUATE SEPARATION MUST BE PROVIDED BETWEEN INDIVIDUAL PIPING, PRESSURE VESSELS AND SPACE STATION STRUCTURE SO AS TO PREVENT PROPAGATION OF FAILURES.</p> <p>ALL CONNECTIONS INVOLVED WITH FLUID TRANSFER MUST BE OF A LEAK-PROOF DESIGN.</p> <p>A LEAK MONITORING SYSTEM MUST BE INSTALLED WHICH PROVIDES DETECTION, LOCATION AND MAGNITUDE OF EACH LEAK.</p>	

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM FLUID MANAGEMENT

PAGE 3 OF 3

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
16	IMPULSE BEYOND PROPULSION SYSTEM CAPABILITIES	SAME AS ITEM 15.	DEPLETION OF PROPULSION SYSTEM PROPELLANT MAY OCCUR BEFORE DEPLETION OF ESCAPING GAS. UNCONTROLLED ROTATION OF SPACE STATION ABOUT AN UNIDENTIFIABLE AXIS WILL RESULT, CAUSING LOSS OF SPACE STATION.	1	DETERMINATION OF THE AMOUNT OF H ₂ /O ₂ PROPELLANT REQUIRED TO COUNTERACT THIS THREAT IS THE RESPONSIBILITY OF WP-02. THE USE OF MOVEABLE TANKS TO MAINTAIN THE SPACE STATION'S CONSTANT CENTER OF GRAVITY MUST BE CONSIDERED IN DETERMINING THE TANK SIZING AND THE AMOUNT OF PROPULSION REQUIRED.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 1 OF 1

ELEMENT/SYSTEM MANUFACTURING & TECHNOLOGY LABORATORY

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
1-27	THESE HAZARDOUS CONDITIONS ARE THE SAME AS THOSE IDENTIFIED FOR THE COMMON MODULE (SEE COMMON MODULE PHA ITEMS 1-18) AND FOR THE ECLSS (SEE ECLSS PHA ITEMS 1-9)				
28	INTRODUCTION OF HAZARDOUS MATERIALS INTO THE SPACE STATION	HAZARDOUS MATERIALS AND PROCESSES USED IN LABORATORY EXPERIMENTS.	CREW INCAPACITATION OR DEATH. LOSS OF MODULE AND/OR SPACE STATION MAY ALSO RESULT.	I	HAZARDOUS MATERIALS USED IN OR PRODUCED BY EXPERIMENTS MUST BE CONTAINED USING A TWO-FAULT TOLERANT DESIGN, SUCH AS TRIPLE CONTAINMENT.
29	HANDLING & DISPOSAL OF HAZARDOUS MATERIALS GENERATED BY EXPERIMENTS	1. SPILLS. 2. LEAKS. 3. HUMAN ERROR. 4. CHEMICAL REACTION. 5. SYNERGISTIC REACTION.	CONTAMINATION OF MODULE'S INTERNAL ATMOSPHERE BEYOND HUMAN/EQUIPMENT TOLERANCE. CONTAMINATION OF EXTERNAL ATMOSPHERE DURING DISPOSAL MAY DESTROY THE SPACE STATION.	I	HAZARD CONTROL STRATEGIES FOR DEALING WITH THIS THREAT HAVE BEEN DEVELOPED; SEE APPENDICES I AND K THROUGH M FOR DETAILS.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

PAGE 1 OF 1

ELEMENT / SYSTEM OMV ACCOMMODATIONS

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
1	EXPLOSION OF PROPELLANTS IN OMV SERVICING AREAS	1. PROPELLANT LEAKS IN PROXIMITY OF IGNITION SOURCE. 2. OVERPRESSURIZATION OF PROPELLANT TANK. 3. COLLISION OF OMV OR FOREIGN OBJECT WITH PROPELLANT TANK.	DESTRUCTION OF SPACE STATION TRUSS, CAUSING LOSS OF SPACE STATION.	I	PROPELLANT TANKS MUST BE PROVIDED WITH METEORITE PROTECTION. THE TANKS MUST BE SEPARATED TO PRECLUDE PROPAGATION OF EXPLOSIONS, AND BARRIERS MUST BE USED TO PREVENT COLLISION BY OMV OR FOREIGN OBJECTS.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM		WP-01 OPERATIONS		PAGE 1 OF 3	
ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
1	NO RESTORATION CAPABILITY FOR SAFETY-CRITICAL SYSTEMS	<p>1. USE OF EXPLOSIVE RELEASE MECHANISMS WILL DAMAGE TRUSS ATTACHMENT POINTS OF SPACE STATION ELEMENTS.</p> <p>2. SAFETY-CRITICAL EQUIPMENT NOT REPAIRABLE DUE TO USE OF WELDED, BRAZED OR SOLDERED JOINTS.</p>	EVENTUAL LOSS OF HABITABILITY DUE TO INABILITY TO RESTORE SAFETY-CRITICAL SYSTEMS IN ORBIT.	I	<p>PYROTECNIC RELEASE MECHANISMS MUST NOT BE ALLOWED AT ATTACHMENT POINTS.</p> <p>WELDING, BRAZING AND SOLDERING MUST NOT BE USED IN CONSTRUCTION UNLESS THEIR REPAIRABILITY IN SPACE CAN BE DEMONSTRATED. THIS REQUIRES AN EXPERIMENT IN SPACE TO PROVE THEIR FEASIBILITY, FOLLOWED BY AN ASTRONAUT TRAINING PROGRAM IF THOSE TECHNIQUES ARE PROVEN FEASIBLE.</p>
2	ROTATION OF PALLETED CARGO ABOUT RMS/WRMS ATTACHMENT POINT	<p>1. AERODYNAMIC DRAG.</p> <p>2. INERTIA.</p>	UNCONTROLLABLE MOMENT MAY ALLOW CARGO TO IMPACT ADJACENT OBJECTS, INCLUDING EVA CREW.	I	<p>FOR SMALL-VOLUME EQUIPMENT THE MOMENT MAY BE SMALL AND, FOR ALL PRACTICAL PURPOSES, NEGLIGIBLE. HOWEVER, FOR EQUIPMENT HAVING LARGER VOLUMES, THE MOMENT CANNOT BE NEGLECTED AND MUST BE GIVEN FURTHER CONSIDERATION.</p> <p>THE DESIGN REQUIREMENT DERIVED FROM THIS SAFETY ANALYSIS SHOULD ADDRESS THE LOCATION OF ATTACHMENT POINTS. IDEALLY, THE ATTACHMENT POINT SHOULD COINCIDE WITH THE CENTERS OF MASS AND PRESSURE. PRACTICALLY, THE ATTACHMENT POINT SHOULD BE AS CLOSE AS POSSIBLE TO THE CENTERS OF MASS AND/OR PRESSURE. IF THERE ARE TWO ATTACHMENT POINTS, THESE POINTS SHOULD FORM A PLANE WITH THE CENTER OF MASS OR PRESSURE SUCH THAT THE PLANE IS PERPENDICULAR TO THE LONGITUDINAL AXIS OF THE EQUIPMENT.</p>

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT/SYSTEM WP-01 OPERATIONS PAGE 2 OF 3

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
3	RMS/MRMS IMPACT WITH NEARBY BODIES	1. INADVERTENT OPERATION. 2. PLANNED OPERATION.	DAMAGE TO IMPACTED OBJECTS AND/OR INCAPACITATION OF CREW.	1	LIMIT TRANSLATION VELOCITY OF OBJECTS SO THAT IMPACT STRESS IS WITHIN TOLERABLE LIMITS.
4	UNWANTED IMPULSE TRANSMITTED TO CREW OR RMS/MRMS DURING EQUIPMENT SEPARATION	ENERGY STORED IN SPRINGS AT ATTACHMENT POINTS.	UNWANTED TRANSLATION OF CREW OR OBJECT. LOSS OF CREWMEMBER(S) AND/OR IMPACT WITH NEARBY OBJECTS MAY RESULT.	1	ENERGY STORED IN SPRINGS AT ATTACHMENT POINTS AND MECHANICAL DISCONNECTS MUST BE EITHER RESTRAINED OR RELEASED SO THAT NO IMPULSE IS TRANSMITTED TO THE CREW OR TO THE RMS/MRMS.
5	INADVERTENT OPERATION OF PAYLOAD PROPULSION SYSTEM DURING TRANSFER	1. CONTROL SYSTEM FAILURE. 2. ELECTROSTATIC DISCHARGE BETWEEN PALLET AND NEARBY BODIES.	UNCONTROLLED TRANSLATION OF PALLET. IMPACT WITH EVA CREWMEMBER(S) AND/OR NEARBY OBJECTS.	1	THE PROPULSION SYSTEM MUST BE INHIBITED DURING TRANSFER. ELECTRICAL CONNECTORS MUST BE DEADFACED AND ELECTROSTATIC POTENTIAL DIFFERENCES BETWEEN THE TWO BODIES MUST BE ELIMINATED PRIOR TO MAKING THE CONNECTIONS.

SPACE STATION WP-01 PRELIMINARY HAZARD ANALYSIS

ELEMENT / SYSTEM WP-01 OPERATIONS

ITEM	HAZARDOUS CONDITION	CAUSE	EFFECT	HAZARD CATEGORY	HAZARD CONTROL
6	HUMAN DEPTH PERCEPTION CAPABILITIES EXCEEDED	SUFFICIENT CUES NOT PROVIDED DURING RMS/MRMS EQUIPMENT TRANSFER.	IMPACT GREATER THAN EQUIPMENT CAN TOLERATE. DAMAGE TO SPACE STATION TRUSS OR MODULE MAY RESULT, CAUSING LOSS OF HABITABILITY.	I	THE RMS/MRMS OPERATION MUST BE CUED FOR DISTANCES LESS THAN 3 METERS FROM TARGET AND MUST BE PROVIDED A MEANS OF VERIFYING THE RMS/MRMS LOCATION WITH RESPECT TO THE SPACE STATION. THE COORDINATE SYSTEM VERIFICATION METHOD MUST BE INDEPENDENT OF ANY NAVIGATION SYSTEM USED TO MANEUVER SPACECRAFT APPROACHING THE SPACE STATION.
7	CREW ENTRY INTO UNINHABITABLE MTL AFTER ATTACHMENT TO TRUSS	MODULE HABITABILITY NOT CHECKED PRIOR TO INITIAL ENTRY.	INJURY OR DEATH OF CREWMEMBERS.	I	MODULE HABITABILITY, INCLUDING SEAL INTEGRITY, MUST BE CHECKED FROM A REMOTE LOCATION (ORBITER AND/OR GROUND) PRIOR TO ENTRY.

without the need to refer to other documents. Complete description of the system and subsystems are provided in the DR-02 End Item Data Books and are not duplicated in this document.

The effect of modes of functional failures (fail open, fail close/short, non-operation, premature operation, and out of sequence operation) of mechanisms, subsystems, systems and control schemes for mechanisms, subsystems, and systems are correlated to higher assemblies until the effect of the assumed failure on the Space Station is identified.

Structural elements, which by definition are single-failure points (common module pressure vessel, secondary structures, pipes, wires, etc.), are not subject to redundancy screening; however, some of these elements have been addressed in the FMEA process to cover failure modes that could cause loss of crew or stations.

Items classified as criticality 1 and 2 in the FMEA, automatically generate a corresponding Hazard Report Form. The Hazard Report Form tracks, in addition to safety issues, criticality 1 and 2, items until resolution and/or hazard risk acceptance by NASA/MSFC (Level C) and/or NASA (Level B) is obtained.

The FMEA effort will initially focus on identified mission and personnel safety critical systems with special attention given to failure effects at the interfaces of subsystems to subsystems, subsystem to systems and work package to work package.

The systems identified for initial study are:

- ECLSS including Thermal Control
- Electrical Power Distribution
- Propulsion

- Laboratory Module and External Payloads
- DMS Distribution Control
- OMV and OTV Accommodations
- Mission and Safety Critical Systems unique to the Logistics Module

Additional systems/subsystems will be added when it is determined that their functions have critical influences on safety, mission or customer access. This information will guide the establishment of redundancy requirements within the system/subsystem or the development of alternate design strategies.

The initial FMEAs will be converted to a bottom-up approach when the level of design detail warrants that conversion. The bottom-up analyses will focus attention on the defined ORUs and will, in general, not go below that level. The results of these more detailed analyses will further refine redundancy, maintainability, sparing and other design selection requirements.

The initial FMEA used a "single thread" (0-failure tolerant) approach to determine criticality category. This method of analysis obviously results in all items being classified as category 1, 2, or 3 (no redundancy). Thus, the criticality categories 1R and 2R become a design requirement until such time that the drawings/ hardware can be inspected. An additional note concerns the capability for the hardware to be:

- a. checked or detected during pre-launch operations or on-orbit,
- b. restored on-orbit, and
- c. becoming a criticality category 1 during periods of removal/replacement.

Answers to these points will be determined as the design, logistics, support and maintenance concepts become finalized.

The completed FMEAs consist of six (6) volumes which are dated June 23, 1986. These volumes are:

1. D483-50045-1, Space Station - Work Package 01 Summary - Preliminary Failure Mode and Effect Analysis - Volume 1.
2. D483-50045-2, Space Station - Work Package 01 Propulsion System Preliminary Failure Mode and Effect Analysis - Vol 2 (WP-02 responsibility).
3. D483-50045-3, Space Station - Work Package 01 OMV and OTV Accommodations Preliminary Failure Mode and Effect Analysis - Volume 3.
4. D483-50045-4, Space Station - Work Package 01 Common Module - Preliminary Failure Mode and Effect Analysis - Volume 4.
5. D483-50045-5, Space Station - Work Package 01 Logistic Module - Failure Mode and Effect Analysis - Volume 5.
6. D483-50045-6, Space Station - Work Package 01 Material Technology Laboratory Module and External Payloads Preliminary Failure Mode & Effect Analysis - Volume 6.

NOTE: The Common Module volume, D483-50045-4, contains the structures/mechanisms, ECLSS, Thermal Control, Communication, Electrical Power, Fluid Management, and Data Management Sub-

system. Within the Data Management section there is a section on application software.

Each of the six volumes titled according to the contract top level Work Breakdown Structure (WBS) is shown in Figure 5.2-1. Each volume is divided into systems and subsystems shown in Figures 5.2-2 through 5.2-7. The FMEA Summary volume summarized the criticality 1 and criticality 2 failures types. The FMEAs for each system and subsystem in volumes 2 through 6 are preceded by a summary description of the system or subsystem analyzed. Where the system complexity allows, the FMEA of the system is combined with that of the subsystem.

The Failure Mode and Effect Analysis Format was established in a joint meeting between MSFC SR&QA, Boeing Aerospace and Martin Marietta. The FMEA data is accessible to MSFC to read only either directly or through tapes or disks. The data is presented in data blocks arranged to fit a report on 8 x 11 paper - instead of the traditional FMEA matrix format. The documentation of the FMEA is accomplished by using a menu driven R:BASE Series 5000 Computer routine on the IBM PC XT. R:BASE is a fully relational data base management system that allows comparison, combinations and manipulations of all or part of any relation stored in the data base. The routine is accessible to the data base input system that resides on the VAX machine and is compatible with RIM. Appendix A to this document contains specific instructions for conducting the FMEA. Appendix B contains instructions for entering the data base.

Boeing Aerospace Company document, schematic, drawing and revision numbering system are used to uniquely identify each FMEA. The FMEA numbering

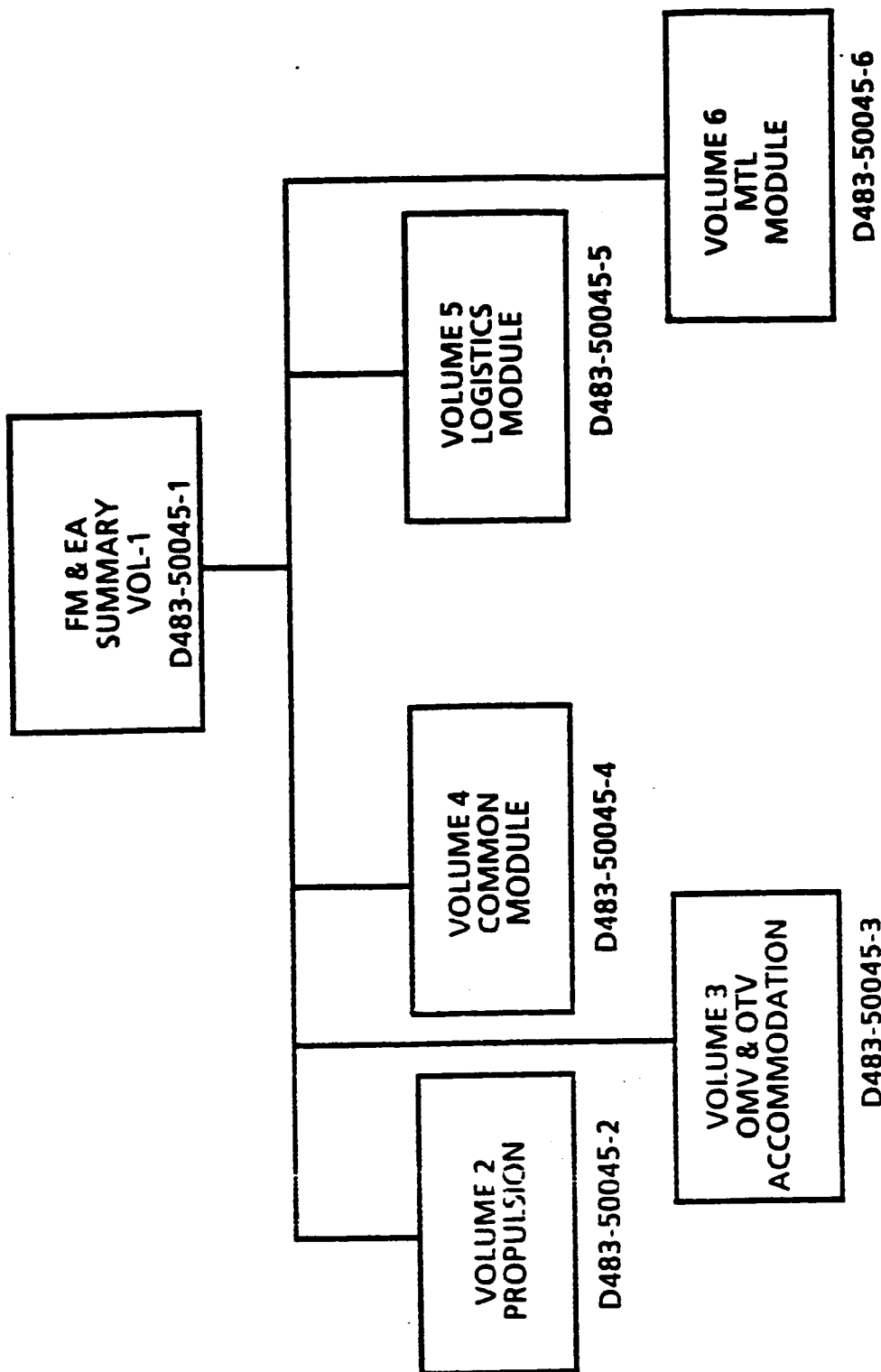


FIGURE 5.2-1 FUNCTIONAL BREAKDOWN

FIGURE 5.2-1 FUNCTIONAL BREAKDOWN

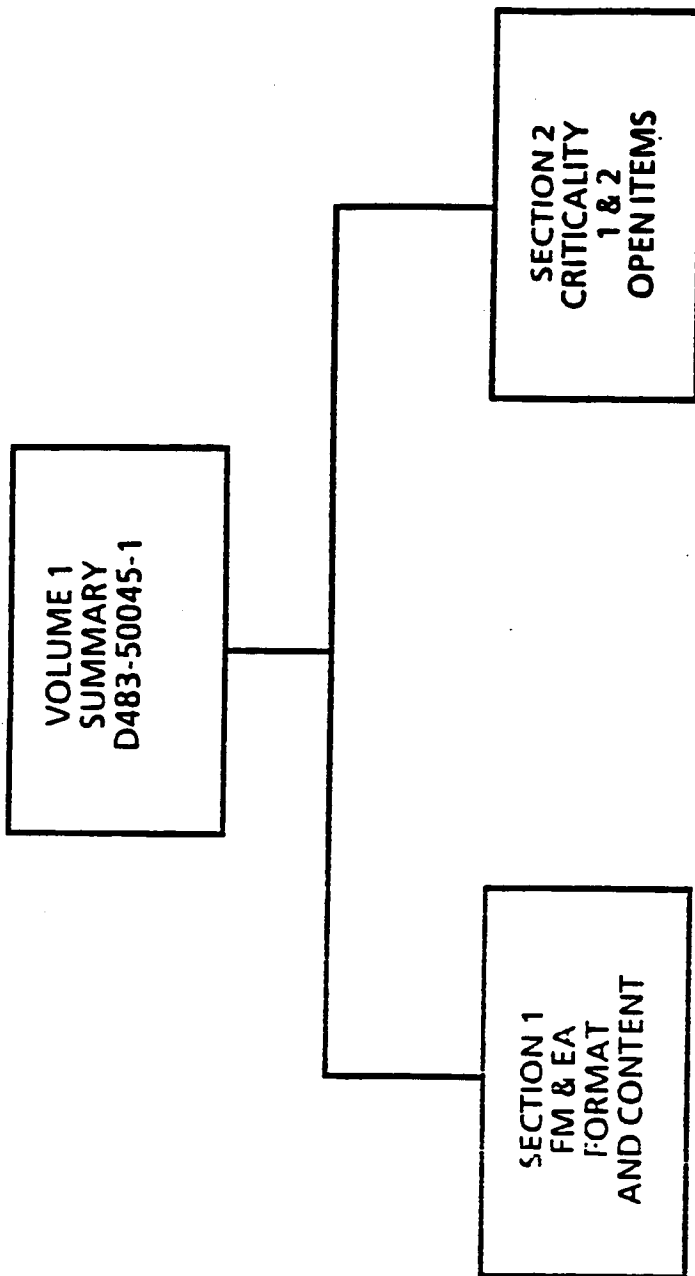


FIGURE 5.2-2 VOLUME 1

FIGURE 5.2-2 VOLUME 1

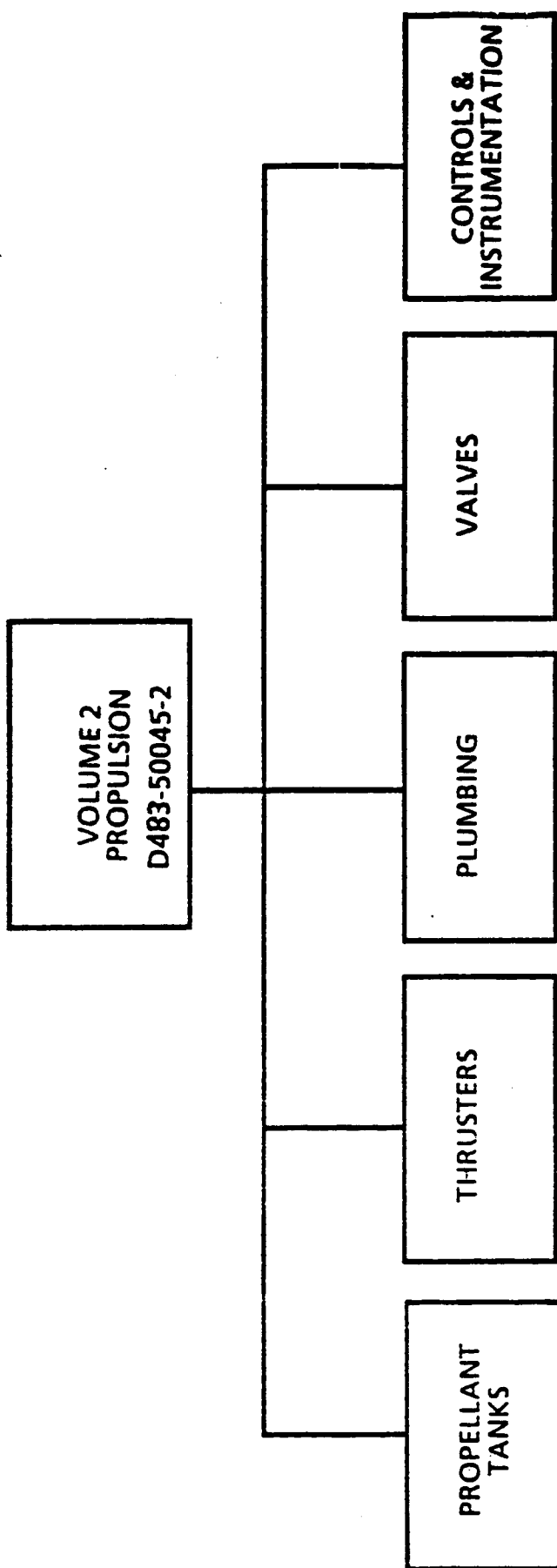
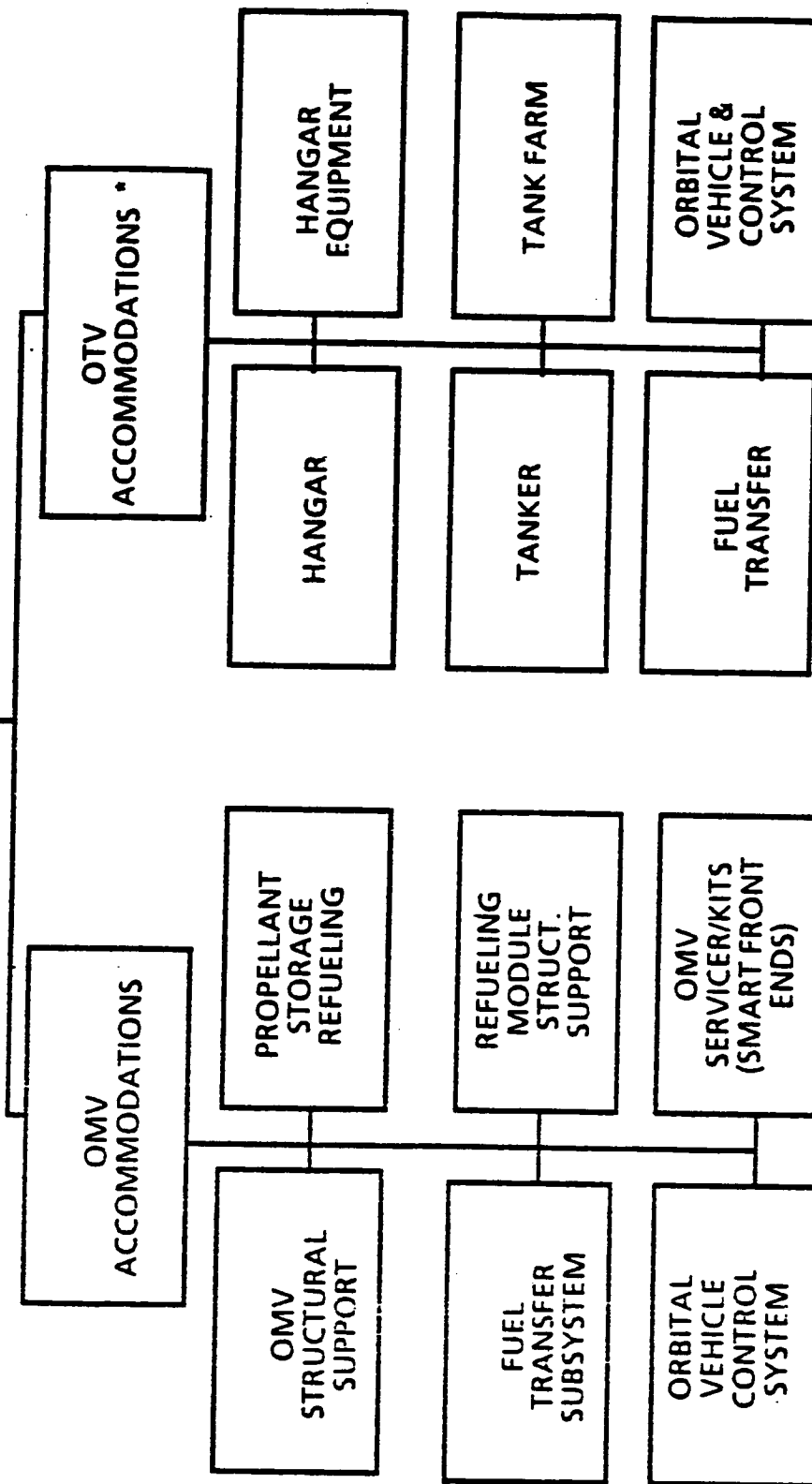


FIGURE 5.2-3 VOLUME 2

FIGURE 5.2-3 VOLUME 2

VOLUME 3
D483-50045-3



* THE OTV WILL NOT BE
ON STATION AT IOC AND
OTV FMEA'S HAVE BEEN
DEFERRED

FIGURE 5.2-4 VOLUME 3

FIGURE 5.2-4 VOLUME 3

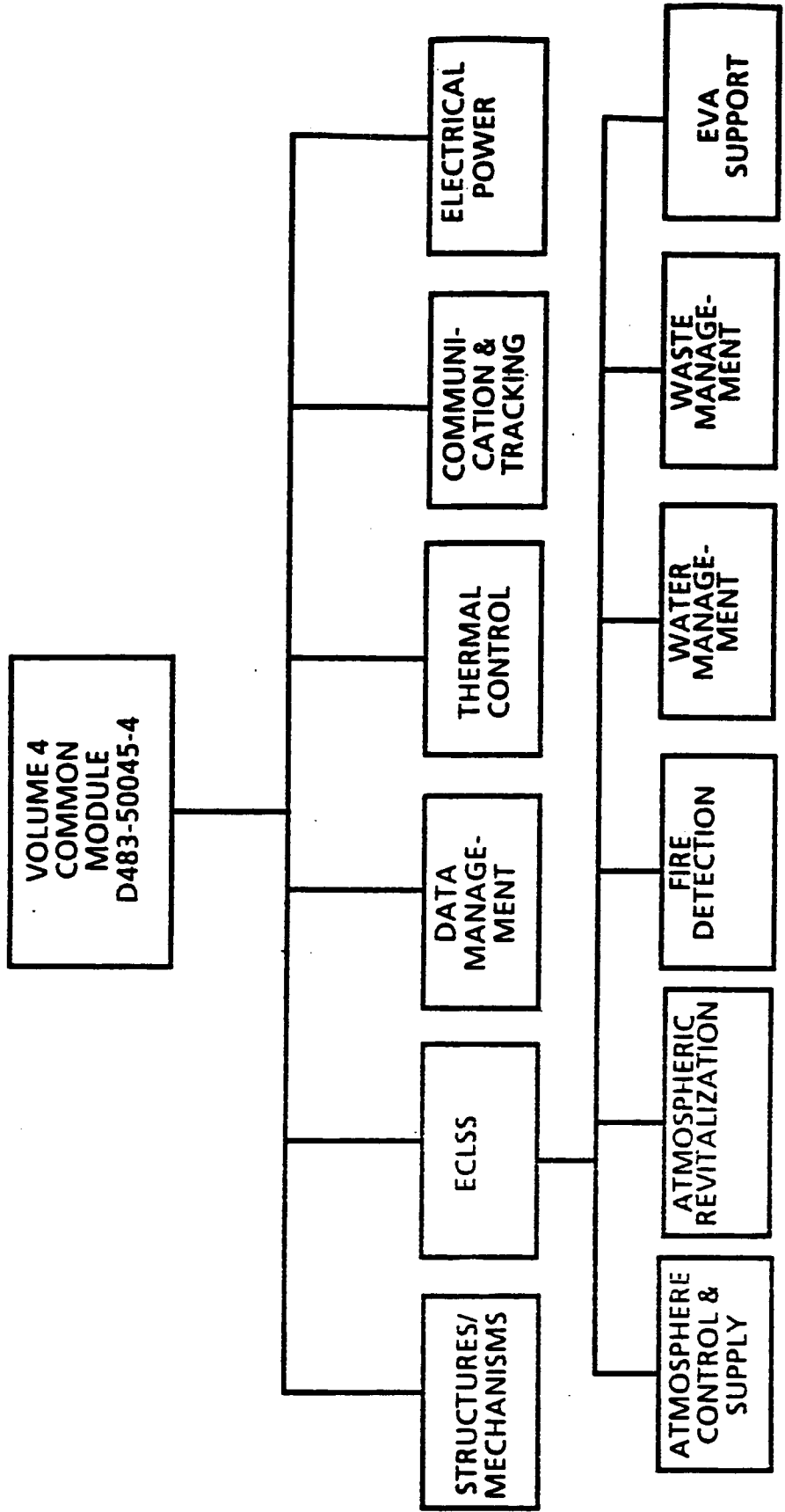


FIGURE 5.2-5 VOLUME 4

FIGURE 5.2-5 VOLUME 4

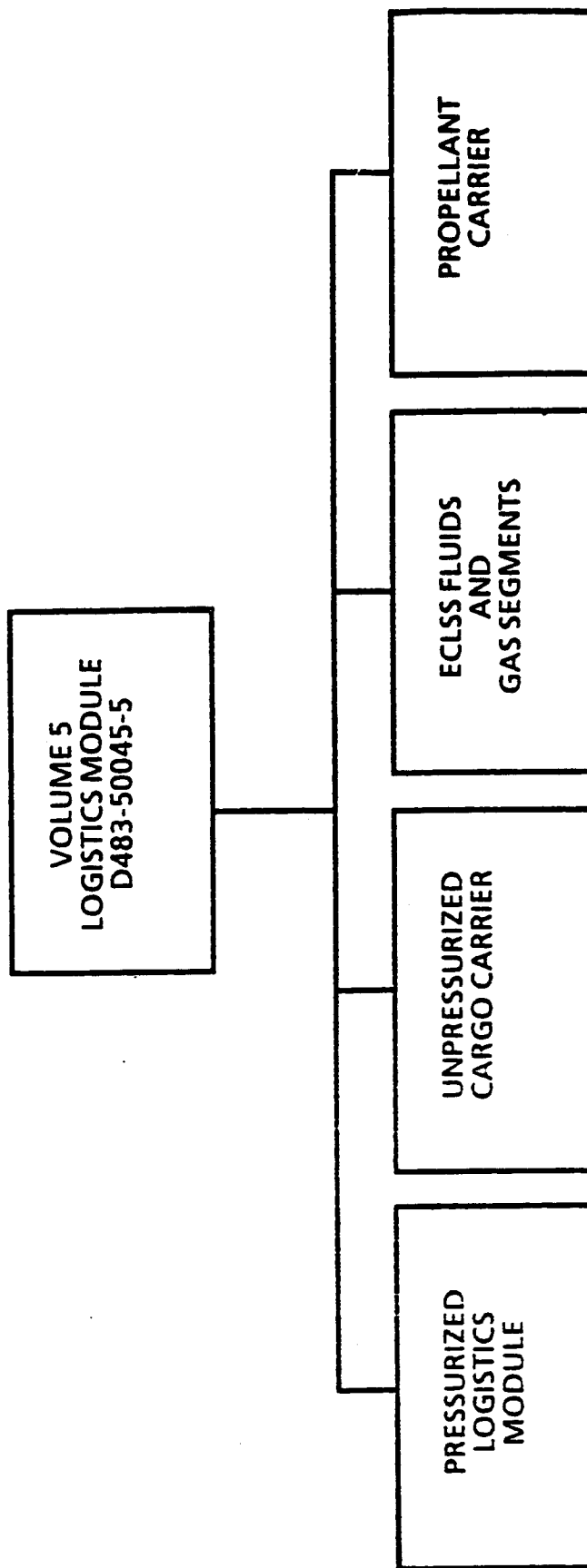


FIGURE 5.2-6 VOLUME 5

FIGURE 5.2-6 VOLUME 5

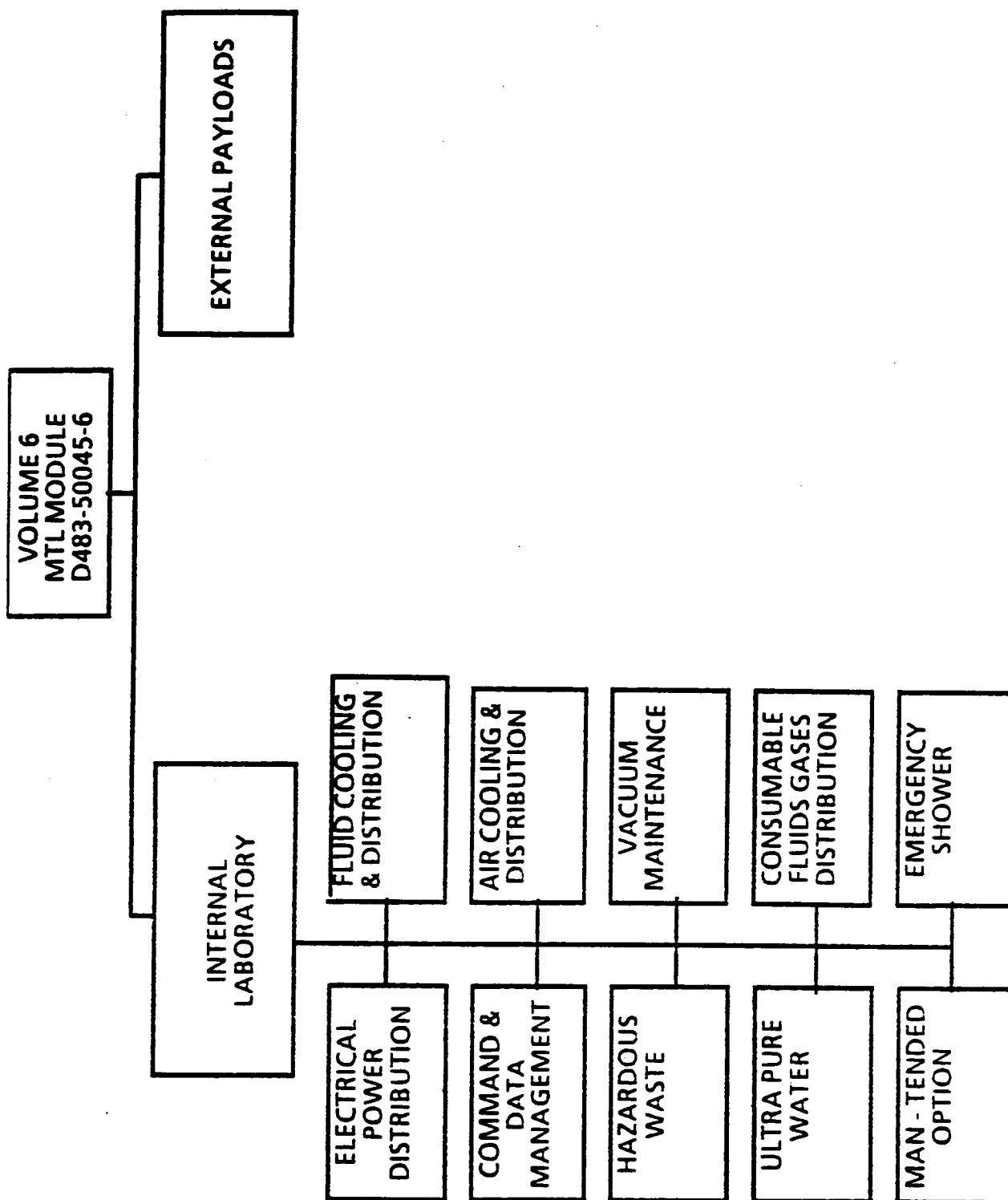


FIGURE 5.2-7 VOLUME 6

FIGURE 5.2-7 VOLUME 6

system is tied directly to the above mentioned systems. The selected FMEA numbering systems is as follows:

Two numbers are used to identify each FMEA. The FMEA number is user generated, broken down by Logistics Support Analysis Control Number (LSACN), system, subsystem, assembly and subassembly. Top level LSACN, through fourth-level are assigned by the Level-B Logistics Integration Center.

The structure number records the path that identifies the position of the FMEA record in the FMEA-tree structure. The FMEA-tree structure is a level by level breakdown of parts (or functions) and their associated components (or subfunctions) until the last known component can be identified. The path is selected from menus that exist within the FMEA application program. Data entries into the FMEA process are defined in Table 5.2-I.

5.2.1 Criticality 1 Items

This paragraph contains the items that are categorized as criticality 1. Single-failure points are identified in the hatch-track mechanism, hatch rollers, hatch seals, and module utility penetrations. All of the other single-failure points are leakage failure modes in the ECLSS and MTL outfitting subsystems. Leakage modes can cause shorting of life-control components and/or cause electrical shock to the crew members. The resolution of this failure mode is:

- a. Provide reasonable precaution against leakage into electrical devices, electrical connections and components of life-critical components, or those capable of resulting in crew electrocution.
- b. Provide absorbent wraps for connections made at panel service ports.
- c. Minimize plumbing/component leakage potential.
 1. Use sealed (brazed, etc.) joint in plumbing; runs.
 2. Specify 0.01 cc/hr. maximum leakage rate on all fluid components.

Preliminary summaries of Criticality 1 items are provided on sheets 155 through 173.

5.2.2 Criticality 2 Items

This paragraph contains the items that are categorized as criticality 2 with the propulsion system excluded. A single thread analysis was used in developing the propulsion system FMEAs and does not reflect the redundancy requirements noted in other volumes.

Preliminary summaries of Criticality 2 items are provided on sheets 174 through 198.

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED
1	FMEA NO.	The FMEA number is user generated, broken down by Logistics Support Analysis Control Number (LSACN), the system, and (if applicable) the assembly, and the subassembly. An example of the numbering system is shown: Example: LB15B-13-1.10.1
2	DATE	Record the date of initial FMEA preparation.
3	MISSION PHASE	Record the point in the Space Station-life cycle being considered. Each mission phase checked must be considered while performing the analysis.
4	REVISION NUMBER	Record the appropriate revision number as assigned by Product Assurance.
5	DATE	Record date revision is prepared.
6	ELEMENT	Record the major WP-01 element being considered i.e., Common Module, Propulsion, OTV/OMV, Laboratory, Logistics Module or Ground Support Equipment.
7	SYSTEM	Record the system within the element being considered, e.g., within the Common Module, the ECLSS.
8	SUBSYSTEM	Record the subsystem within the system being considered e.g., within the ECLSS CO ₂ removal.

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES (Cont'd)

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED
9	DRAWING NUMBER	Record the drawing/sketch/layout number of the subsystem being evaluated.
10	BLOCK DIAGRAM NUMBER	Record the functional block diagram number of the subsystem being evaluated.
11	LSACN NUMBER	Logistics will add this number at later phases of the program as part of the Logistics Support Analysis process. LSACN (Logistics Support Analysis Control Number).
12	ITEM NUMBER	Usually entered as 1; each item number (and those following sequentially), represents a breakdown of the current system, subsystem, or assembly level to one level lower only.
13	ITEM NOMENCLATURE	Record the technical description of the item/function in sufficient detail to understand what item or function is e.g., Valve mixing, switch, DPDT.
14	FUNCTIONAL DESCRIPTION	Record the operating characteristics of the item identified in location 13 and describe its function within the sub system being assessed.
15	FAILURE MODE	Consider each of these five failure modes in turn. 1) Fail open, 2) Fail short/closed, 3) Fail to operate, 4) Premature operation and 5) Out of sequence operation. Each applicable failure mode should be evaluated.

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES (Cont'd)

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED								
16	CRITICALITY CATEGORY	<p>Record the appropriate criticality category based on the following:</p> <table><tr><th>Category</th><th>Definition</th></tr><tr><td>1</td><td>Could result in loss of Station, Station element, or flight or ground crew.</td></tr><tr><td>2</td><td>Could result in loss or suspension of mission operations capability. For Ground Support Equipment (GSE), category 2 is loss of Space Station subsystem.</td></tr><tr><td>3</td><td>All others.</td></tr></table> <p>1R Redundant hardware elements the loss of which could result in loss of flight or ground crew, Station, or Station element.</p> <p>2R Redundant hardware elements the loss of which could result in loss or suspension of mission operations capability.</p> <p>For additional information see location description 21</p>	Category	Definition	1	Could result in loss of Station, Station element, or flight or ground crew.	2	Could result in loss or suspension of mission operations capability. For Ground Support Equipment (GSE), category 2 is loss of Space Station subsystem.	3	All others.
Category	Definition									
1	Could result in loss of Station, Station element, or flight or ground crew.									
2	Could result in loss or suspension of mission operations capability. For Ground Support Equipment (GSE), category 2 is loss of Space Station subsystem.									
3	All others.									
17	FAILURE CAUSE(s)	<p>Describe the condition(s) that could result in the failure mode (reference location number 15) being considered. These may include simple wear-out or breakage, over-stressing, inadvertent commanding or lack of command. Sufficient detail should be provided so that the failure mechanism can be understood.</p>								

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES (Cont'd)

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED
18	FAILURE EFFECT ON FUNCTION	Describe the effect of the failure on the function/subsystem discounting any redundancy or availability from other sources.
19	FAILURE EFFECT ON NEXT HIGHER ASSEMBLY	Describe the effect(s) of the failure on the system discounting any redundancy or function availability from other sources.
20	FAILURE EFFECT ON SYSTEM/ ELEMENT	Describe the effect(s) of the failure on the element discounting any redundancy or function availability from other sources.
21	FAILURE EFFECT ON MISSION/ CREW	First, describe the effect(s) of the failure on the mission/crew discounting any redundancy or function availability from other sources. Second, justify the assignment of criticality category 1R and 2R in terms of redundancy, success paths remaining and function availability from other sources. This information provides the basis for the retention of 1R and 2R items.
22	FAILURE DETECTION METHODS	Describe parameters that will indicate function/item failure and location. These will be used as inputs to failure monitoring systems including the crew.
23	DETECTION TIME	Record time interval from failure until the parameters identified in location 22 will manifest in themselves, i.e., How long before the monitoring system or crew knows a failure has occurred and the failure location.

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES (Cont'd)

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED
24	TIME TO REPAIR	Two pieces of data are required. First, how quickly must the failure be corrected for reasons of operational criticality. Second, how long will the corrective action take based on tasks to be done. These two pieces of data will initially be based on best engineering judgment and will be refined as WP-01 and other Space Station elements definitions mature.
25	REPLACEMENT LEVEL	Describe the most logical "break points" in the subsystem for failure correction, e.g., card, module, entire subsystem, etc. The data combined with other maintainability and logistic inputs will be used to aid in defining ORUs.
26	REMARKS/ CORRECTIVE	Record any clarifying comments or assumptions that apply to data at any FM&EA worksheet location. Additionally, describe the approach to be used to resolve problems such as missing data or category 1 or 2 type failures.
27	STRUCTURE NUMBER	The structure number is an FMEA database System-generated number that records the path to identify the position of the FMEA tree structure. The FMEA tree structure is a level-by-level breakdown of parts (or functions) and their associated components (or subfunctions) until the last known component can be identified. The path is selected from menus that exist within the FMEA application program. The structure number has a format of numbers separated by dots or periods.

TABLE 5.2-I FMEA DESCRIPTION OF ENTRIES (Concluded)

LOCATION NUMBER	LOCATION TITLE	DATA REQUIRED
28	INTERNAL PART NUMBER (INTRNLPN)	The internal part number is an internal counter within the FMEA application program that sequentially counts each entry of each particular FMEA number. It gives number of the occurrence under the same FMEA number. The INTRNLPN is used in printing reports, sorting and other internal process only.

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST02-1-6

NOMENCLATURE: Seal Hatch

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Loss of crew and mission, depending on leak rate and location of hatch.

FAILURE MODE

Fails to function.

FAILURE CAUSE

Mechanical damage due to rupture, shock/collision, deterioration.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace damaged seal.

*** Per NASA direction,

criticality category 1 failure items must be 2 - fault tolerant. ***

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST06-1-6

NOMENCLATURE: Hatch Track

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Could trap crew depending on hatch location.

FAILURE MODE

Fail to operate.

FAILURE CAUSE

Deformed track race or damaged/jammed rollers.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Alternate hatch available for escape to adjoining module (2 - fault tolerant). Realign track structure/replace damaged track as required.

Single failure point in airlock.

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST09-1-6

NOMENCLATURE: Rollers, Hatch

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Could trap crew depending on hatch location.

FAILURE MODE

Fail to operate.

FAILURE CAUSE

Mechanical damage/deformation.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Alternate hatch available to escape to adjoining module (2 - fault tolerant).

*** Per NASA direction, criticality category 1 failure items must be 2 - fault tolerant. Single failure point.

SYSTEM: MTL OUTFITTING

SUBSYSTEM: INTERNAL LAB

FMEA No: LB10F-13-1.10

NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Loss of MTL operations requiring process fluid. Leakage will pose hazard to crew.

FAILURE MODE

Internal leakage.

FAILURE CAUSE

Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Repair/replace damaged component. Use double walled insulated carrier. + Two fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB12F-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Loss of MTL operations requiring process fluid. Will pose hazard to crew.

FAILURE MODE

Internal leakage.

FAILURE CAUSE

Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Could cause fire hazard. Use sealed (brazed joints) in plumbing runs. Specify 0.01 cc/hr maximum leakage rate on all fluid components. Use double wall insulated carrier.
* Two fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB14E-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Loss MTL operations needing process fluid. Internal leakage poses hazard to crew.

FAILURE MODE

Internal/External leakage

FAILURE CAUSE

Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Repair/replace damaged item. * Use sealed (brazed) joints in plumbing runs. Specify 0.01 cc/hr maximum leakage rate on all fluid components.
* Two fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB13A-13-1.12 NOMENCLATURE: Storage Tank

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Possible electrocution of crew. Lose function of MTL water processes.

FAILURE MODE

External leakage.

FAILURE CAUSE

Mechanical shock; mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Minor repair by crew, otherwise repair/replace at 90 day resupply (GRU). *Use sealed (brazed) joints in plumbing run.

Specify 0.01 cc/hr maximum leakage rate on all fluid components.

* Two

fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB13I-13-1.12 NOMENCLATURE: Tubings and Fittings

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Could be hazardous to crew. Lose function of MTL water processes.

FAILURE MODE

External leakage.

FAILURE CAUSE

Mechanical shock; mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Repair/replace damaged item.

* Two fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB196-13-1.13 NOMENCLATURE: Tank, Water Supply With Bladder

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Depending on location, could cause incapacitation of crew.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
Piece part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace defective item. Requires special design attention, ie., brazed joints, specify .01/hr. leak rate criteria.
* Two fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB26F-13-1.6 NOMENCLATURE: Pump Package Assembly

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Incapacitation of crew and or damage to MTL module.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
Loss of input.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Upon failure detection, turn off power to pump package, switch to redundant pump if required. Inspect to see if the problem is electrical or mechanical. Look for leaks at the pump assembly. Remove the pump pkg from mount and disconnect QD's on both inlet/outlet. Replace w/new unit.* require 2 FT.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB26M-13-1.6 NOMENCLATURE: Rack Water Flow Control Valve.

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Possible multiple experiment shutdown.

FAILURE MODE
External/internal leakage.

FAILURE CAUSE
Piece part structural failure, vibration, high pressure,

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

** Detection method continued ** Water flow rate to each rack will be detected. Water temperature and pressure at inlet and outlet to each rack will be detected. Upon detection, shut off valves upstream and downstream of leak, remove and replace pipe.
* Two fault tolerance is required

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB17D-13-1.8 NOMENCLATURE: Pipe.

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Damage to the station in module overpressurization.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
 Mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

* Two fault tolerance is required. * Use double isolated welded carrier. * Specify 0.01 cc/hr maximum leakage rate on all fluid components.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB17E-13-1.8 NOMENCLATURE: Interface, Bulkhead Feed Thru

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Crew must evacuate MTL.

FAILURE MODE
External leakage.

FAILURE CAUSE
Mishandling, abuse, loss of/improper input.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
* Two fault tolerance design is required. * Caution and warning system shall monitor pressure and temperature of the vital area of the vacuum vent system. * Need to provide an I/F MTL DMS system in order to control user access to the vent system.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB16E-13-1.9 NOMENCLATURE: Interface, Bulkhead Feed Thru

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Crew must evacuate MTL.

FAILURE MODE
External leakage.

FAILURE CAUSE
Mishandling, abuse, loss of/improper input.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
* Two fault tolerance is required. * Caution and warning system shall monitor pressure and temperature of the vital area of the vacuum vent system. * Need to provide an I/F MTL DMS system in order to control user access to the vent system.

SYSTEM: ELECTRICAL POWER DISTRIBUTION SUBSYSTEM: DISTRIBUTION EQUIPMENT
FMEA No: EP01-4-3 NOMENCLATURE: Power Penetration

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Possible loss of crew due to loss of cabin pressure.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
 Mishandling or abuse and/or piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Primary power penetration-Module depressurization and repressurization with EVA required.
* two fault tolerance is required.

SYSTEM: THERMAL CONTROL SUBSYSTEM: HEAT ACQUISITION TRANSPORT-INTERNAL
FMEA No: TCO1A6-5-1.1 NOMENCLATURE: Accumulator

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Possible crew electrocution, equipment shorting.

FAILURE MODE
Fail to operate.

FAILURE CAUSE
Internal or external leakage.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Internal/External-Leakage indication on DMS CRT display. Replace pump package.
** Two fault tolerance is required.

SYSTEM: ECLSS SUBSYSTEM: ATMOSPHERE CONTROL & SUPPLY
FMEA No: EC07A-7-2.4.2 NOMENCLATURE: Oxygen Flow Control System

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Possible change to degraded level atmosphere of control.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
High pressure, part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Redundant installation. * Two fault tolerance is required.

SYSTEM: ECLSS SUBSYSTEM: ATMOSPHERE REVITALIZATION
FMEA No: EC05-7-3.3.1 NOMENCLATURE: Oxygen Generation System

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Supply of O2 could degrade to hazardous levels resulting in safe haven.

FAILURE MODE
Leakage.

FAILURE CAUSE
Part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Redundant installation. Loss of this system breaks the life support cycle and stops CO2 reduction which is dependent on the hydrogen produced in this step. This stoppage in turn impacts the potable water supply. ** Two fault tolerance is required.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC156-7-5.1.1 NOMENCLATURE: Plumbing, Urine Collection

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution, electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level. Repair or replace faulty components. ** Two fault tolerance is required. * Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18K-7-5.1.2 NOMENCLATURE: Evaporative Water Processing Unit

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution. Electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt, switch to redundant system on other module, repair or replace faulty component.
** Two fault tolerance is required. * Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18K2-7-5.1.3 NOMENCLATURE: Urine Water Quality Monitor

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Possible crew poisoning, electrocution, equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant next level higher system, patch or replace faulty component.

* Two fault tolerance is required. * Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18Q4-7-5.2.1 NOMENCLATURE: Condensate Collection Tank

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Crew electrocution or electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Electrical interrupt below danger level. Redundant system in other module takes over. Remove and replace leaking tank.

** Two fault tolerance is required. * Use sealed (brazed) joint plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail component.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18L1-7-5.2.2 NOMENCLATURE: Multifiltration Unit

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Electrocution of crew. Electrical equipment shorting, cabin contamination.

FAILURE MODE

Leakage.

FAILURE CAUSE

Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant system, patch or replace faulty component.

* Two fault tolerance is required.

* Use sealed (brazed) joints in plumbing runs. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18M2-7-5.2.3 NOMENCLATURE: Water Quality Monitor

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Possible poisoning.

FAILURE MODE

Leakage.

FAILURE CAUSE

Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant next level higher system. Patch or replace faulty component.

* Two fault tolerance is required. * Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC1806-7-5.2.4 NOMENCLATURE: Potable Water Storage Tanks

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure. (plumbing, tankage.)

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level. Switch to redundant system in other module, repair or replace faulty component.
* Two fault tolerance is required.* Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC1805-7-5.2.5 NOMENCLATURE: Potable Water Resupply System

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure (plumbing, tankage)

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger threshold. Backup supplied by emergency potable water supply. Remove and replace faulty component or patch. * Two fault tolerance is required.* Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18Q-7-5.2.6 NOMENCLATURE: Potable Water Distribution System

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level. Switch to redundant system in other module or bypass faulty component. Repair or replace faulty component. * Two fault tolerance is required. *Use sealed (brazed) joint in plumbing run. Specify 0.01 cc/hr maximum leakage on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18SB-7-5.2.7 NOMENCLATURE: Oral Hygiene Station

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level. Use unit in other module, repair or replace. Repair faulty equipment.
** Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC18Q2-7-5.3.1 NOMENCLATURE: Waste Collection Tank

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Electrocution of crew, electrical equipment shorting, cabin contamination.

FAILURE MODE

Leakage.

FAILURE CAUSE

Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant system in other module, repair by patching or replacing faulty component. Electrical interrupt below danger threshold. * Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY AND MANAGEMENT
FMEA No: EC18Q12-7-5.3.2 NOMENCLATURE: Plumbing, Hygiene Water.

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Electrocution of crew, electric equipment shorting, cabin contamination.

FAILURE MODE

Leakage.

FAILURE CAUSE

Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Electrical interrupt below danger threshold. Switch to redundant system in other module, repair by patching or replacing faulty component. * Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY AND MANAGEMENT
FMEA No: EC1BL1-7-5.3.3 NOMENCLATURE: Multifiltration Unit

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution, electrical equipment shorting, cabin contamination.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level.
** Two fault tolerance is required **.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC1BL2-7-5.3.4 NOMENCLATURE: Hygiene Water Quality Monitor

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger level. Switch to redundant next level higher system, patch or replace faulty component.
* Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC1803-7-5.3.5 NOMENCLATURE: Hygiene Water Storage Tanks

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, equipment damage.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure (plumbing, tankage).

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger threshold. Switch to redundant system in other module, repair or replace faulty component.
** Two fault tolerance is required. * Use sealed (brazed) joints in plumbing runs. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS SUBSYSTEM: WATER RECOVERY & MANAGEMENT
FMEA No: EC180-7-5.3.6 NOMENCLATURE: Hygiene Water Distribution System

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Switch to redundant system in other module or bypass faulty component. Repair or replace faulty component. Electrical interrupt below danger levels. * Two fault tolerance is required. * Use sealed (brazed) joints in plumbing runs. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS
FMEA No: EC18S1-7-5.3.7 NOMENCLATURE: Shower

SUBSYSTEM: WATER RECOVERY & MANAGEMENT

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Electrical interrupt below danger threshold. Take sponge baths and repair. ** Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 maximum leakage rate on all fail components.

SYSTEM: ECLSS
FMEA No: EC18S5-7-5.3.8 NOMENCLATURE: Handwash

SUBSYSTEM: WATER RECOVERY & MANAGEMENT

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution, electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Use redundant unit and repair. Electrical interrupt below danger level.
** Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage on all fail components.

SYSTEM: ECLSS
FMEA No: EC16A-7-6.1.1 NOMENCLATURE: Urinal

SUBSYSTEM: WASTE MANAGEMENT

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, electrical shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Clean up leakage, switch to redundant system, repair or replace. Electrical interrupt below danger level. ** Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: ECLSS
FMEA No: EC18Q1-7-6.4.1 NOMENCLATURE: Urine Brine Storage Tank

SUBSYSTEM: WASTE MANAGEMENT

CRITICALITY ID: 1

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Electrocution of crew, electrical equipment shorting.

FAILURE MODE
Leakage.

FAILURE CAUSE
Piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Repair leak, electrical interrupt below danger level. * Two fault tolerance is required. * Use sealed (brazed) joints in plumbing run. Specify 0.01 cc/hr maximum leakage rate on all fail components.

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST01-1-6

NOMENCLATURE: Plate Hatch (Primary Structure)

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Limits mission and imposes repair time on crew.

FAILURE MODE

Fails to operate.

FAILURE CAUSE

Mechanical damage due to rupture, shock/collision.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Alternate hatch available for escape to adjoining module (1-fault tolerant) Repair structural damage from collision or material rupture.

*** Primary Structure failure 1-2

fault tolerant waived in SOW 2.1.10.1 ***

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST12-1-6

NOMENCLATURE: Shutter 20 Inch Diameter Window

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Restriction of operations.

FAILURE MODE

Fails to operate.

FAILURE CAUSE

Mechanical failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Shuttle OMV/DTV docking may inhibited, and the mission delayed or aborted (0-fault tolerant).

*** Per NASA direction, criticality category 2 failure items must be 1 - fault tolerant.

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST13-1-6

NOMENCLATURE: Mechanism, 20 Inch Diameter Shutter

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Restricts operation.

FAILURE MODE

Fails to operate.

FAILURE CAUSE

Mechanical damage due to shock collision.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Shuttle, OMV/OTV docking may be inhibited.

*** Per NASA direction, criticality category 2 failure

items must be 1 - fault tolerant. ***

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST14-1-6

NOMENCLATURE: Panel, Meteoroid Debris

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Imposes unscheduled maintenance in crew.

FAILURE MODE

Fail to operate.

FAILURE CAUSE

Mechanical damage due to shock collision.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace damaged panels. *** detection time is immediate upon EVA or Closed Circuit TV (CCTV) ***

** Per NASA direction, criticality category 2 failure items must be 1 - fault tolerant. ***

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST15-1-6

NOMENCLATURE: Gauge, Pressure

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Impose unscheduled maintenance on crew.

FAILURE MODE

Pressure reading error.

FAILURE CAUSE

Mechanical damage due to shock collision.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace gauge assembly.

* One fault tolerance is required.

SYSTEM: PRIMARY STRUCTURE

SUBSYSTEM: STRUCTURES/MECHANISMS

FMEA No: ST16-1-6

NOMENCLATURE: Valve, Equalization

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Imposes unscheduled maintenance requirements on crew.

FAILURE MODE

Fail open.

Fail closed.

FAILURE CAUSE

Defective valve.

Shock/collision.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace valve assembly.

*** One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB10B-13-1.10 NOMENCLATURE: Quick Disconnects

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced MTL operations requiring process fluid.

FAILURE MODE
Piece-part structural failure.
Fails to open/close.
External leakage.

FAILURE CAUSE
Mishandling or abuse, mechanical shock.
Mishandling or abuse; mechanical shock.
Mishandling or abuse; Mechanical shock.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace Quick disconnect hose. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB10F-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE
Structural failure.
External leakage.

FAILURE CAUSE
Mechanical shock, mishandling or abuse.
Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Repair/replace damaged component. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB11C-13-1.10 NOMENCLATURE: Quick Disconnect

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced MTL operations requiring process fluid.

FAILURE MODE

Physical binding/jamming.
Fails to open/close.
External leakage.

FAILURE CAUSE

Mishandling or abuse;mechanical shock.
Mishandling or abuse;mechanical shock.
Mishandling or abuse;mechanical shock.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace Quick disconnect hose or assembly. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB11I-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE

Structural failure.
Internal leakage.
External leakage.

FAILURE CAUSE

Mechanical shock;mishandling or abuse.
Mechanical shock, mishandling or abuse.
Mechanical shock;mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Damaged. ** Use double wall insulated wall vessel/tubing. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB12B-13-1.10 NOMENCLATURE: Quick Disconnect

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced MTL operations requiring process fluid.

FAILURE MODE	FAILURE CAUSE
Physical binding/jamming, fails to open/close, external	Mishandling or abuse; Mechanical shock.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace Quick disconnect hose. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB12E-13-1.10 NOMENCLATURE: Storage Tank

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE	FAILURE CAUSE
Structural failure, external leakage.	Mechanical Shock; mishandling or abuse

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Damaged tank not repairable in orbit, replace at next logistics cycle. Use double wall insulated carrier vessel.
* One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB12F-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE
Structural failure.
External leakage.

FAILURE CAUSE
Mechanical shock; mishandling or abuse.
Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Double wall insulated carrier. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB14D-13-1.10 NOMENCLATURE: Storage Tank

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE
Structural failure.
External leakage.

FAILURE CAUSE
Mechanical shock;mishandling or abuse.
Mechanical shock;mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Damaged tank not repairable in orbit; replace at next logistics cycle.
tolerance waived IAW SOW 2.1.10.1(In accordance with IAW.)

* One fault

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB14E-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE
Structural failure.

FAILURE CAUSE
Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Repair/replace damaged item. * One fault tolerance is required with manual
override.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB15B-13-1.10 NOMENCLATURE: Quick Disconnects

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced MTL operations requiring process liquid.

FAILURE MODE
External leakage, external leakage, fails to open/close. FAILURE CAUSE
Mishandling or abuse; Mechanical shock.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace quick disconnect hose. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB15F-13-1.10 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of MTL operations requiring process fluid.

FAILURE MODE
Structural failure.
Internal/External leakage

FAILURE CAUSE
Mechanical shock, mishandling or abuse.
Mechanical shock, mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Repair/replace damaged item. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB28A-13-1.11 NOMENCLATURE: Application Software

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Degraded MTL performance.

FAILURE MODE
Erroneous indication, fails to start/stop, erroneous

FAILURE CAUSE
Temperature (high/low), procedural error, loss of improper input

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Uplink new software. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB13H-13-1.12 NOMENCLATURE: Quick Disconnects

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced MTL operations requiring process water.

FAILURE MODE	FAILURE CAUSE
Physical binding/jamming, fails to open/close, external	Mechanical shock; mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace Quick disconnect hose. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB13I-13-1.12 NOMENCLATURE: Tubing and Fittings

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Reduced or eliminated MTL operations requiring process water.

FAILURE MODE	FAILURE CAUSE
Structural failure.	Mechanical shock; mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Repair/replace damaged item. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB19C-13-1.13 NOMENCLATURE: Shower Enclosure

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Removes safety feature.

FAILURE MODE	FAILURE CAUSE
Structural failure, Physical binding/abuse, fails to open.	Mishandling/abuse

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace defective item. * 1 fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB19D-13-1.13 NOMENCLATURE: Hand Held Sprayer

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Removes safety feature.

FAILURE MODE	FAILURE CAUSE
Internal/External leakage, fails to open.	Mishandling/abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace defective item. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB19E-13-1.13 NOMENCLATURE: Gas Charge Tank for Shower Enclosure

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Removes safety feature.

FAILURE MODE
Fails to supply, internal/external leak.

FAILURE CAUSE
Mishandling/abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace defective item. *One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB19G-13-1.13 NOMENCLATURE: Tank, Water Supply With Bladder

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Removes safety feature.

FAILURE MODE
Fails to supply.

FAILURE CAUSE
Mishandling/abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace defective item. * One fault tolerance is required.

SYSTEM: MTL OUTFITTING

SUBSYSTEM: INTERNAL LAB

FMEA No: LB19J-13-1.13

NOMENCLATURE: Vacuum Attachment

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Possible contamination of shower area.

FAILURE MODE

Fail to operate, Fail to open.

FAILURE CAUSE

Mishandling/abuse, piece-part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace defective item.

* One fault tolerance is required.

SYSTEM: MTL OUTFITTING

SUBSYSTEM: INTERNAL LAB

FMEA No: LB29A-13-1.14

NOMENCLATURE: Teleoperated Robotic Device

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Possible loss of meaningful MTO mission (no crew).

FAILURE MODE

Erratic operation, physical binding/jamming, fails out of

FAILURE CAUSE

Loss of proper inputs, temperature (high/low), mishandling or

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

MTO teleoperated/robotic device's compatible with crew.

* One fault tolerance is required.

**

time to repair - weeks, next orbiter.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB26L-13-1.6 NOMENCLATURE: Flex Hoses

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Imposes unscheduled maintenance on crew.

FAILURE MODE
Physical binding/jamming.

FAILURE CAUSE
Mishandling/abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Upon fault detection, shut off the valves upstream and downstream of the leak.
* One fault tolerance is required.

SYSTEM: MTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB17A-13-1.8 NOMENCLATURE: Main Shut Off Valve (Electrical)

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Damage to MTL module in overpressurization.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
Mishandling or abuse, loss of/improper input.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
* One fault tolerance is required.

SYSTEM: NTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB16Q-13-1.9 NOMENCLATURE: Waste Storage Tank

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Imposes unscheduled maintenance on crew.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
Mishandling or abuse, piece/part structural failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
On orbit repairable/replaceable by outfitting crew. Repair time: EVA - 6 hours, next resupply.
* One fault tolerance is required.

SYSTEM: NTL OUTFITTING SUBSYSTEM: INTERNAL LAB
FMEA No: LB18J-13-1.12 NOMENCLATURE: Waste Storage Tank

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Restrict experiment operations.

FAILURE MODE
Internal/External leakage

FAILURE CAUSE
Mishandling or abuse.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
On orbit repairable/replaceable by outfitting crew. * One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION SUBSYSTEM: WIRE BUNDLES AND CONNECTORS
FMEA No: EP10-4-1 NOMENCLATURE: Wire Bundles and Connector Equipment

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Shorted.
Open (electrical).
Leakage (electrical).

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string a replacement cable.

** One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION SUBSYSTEM: WIRE BUNDLES AND CONNECTORS
FMEA No: EP11-4-1 NOMENCLATURE: Secondary Cable

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Shorted.
Open (electrical)

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string a replacement cable.

+ One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION
FMEA No: EP12-4-1 NOMENCLATURE: Load Cable

SUBSYSTEM: WIRE BUNDLES AND CONNECTORS

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Shorted.
Open (electrical).
Leakage (electrical).

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string replacement cable.

* One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION
FMEA No: EP13-4-1 NOMENCLATURE: Battery Cable

SUBSYSTEM: WIRE BUNDLES AND CONNECTORS

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Shorted.
Open (electrical).
Leakage (electrical).

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.
Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string a replacement cable.

* One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION SUBSYSTEM: WIRE BUNDLES AND CONNECTORS
FMEA No: EP14-4-1 NOMENCLATURE: Lighting Cable

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Leakage (electrical).

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string a replacement cable.

* One fault tolerance is required.

SYSTEM: ELECTRICAL POWER DISTRIBUTION SUBSYSTEM: WIRE BUNDLES AND CONNECTORS
FMEA No: EP15-4-1 NOMENCLATURE: Bulkhead Feed Thru

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

The effect on mission is dependent upon the power users functional criticality

FAILURE MODE

Shorted.

Open (electrical).

Leakage (electrical).

FAILURE CAUSE

Mishandling or abuse and/or piece-part failure.

Mishandling or abuse and/or piece-part failure.

Mishandling or abuse and/or piece-part failure.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Remove faulty cable and string a replacement cable.

* One fault tolerance is required.

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT ACQUISITION TRANSPORT-INTERNAL

FMEA No: TC01A7-5-1.1

NOMENCLATURE: Quick Disconnect Coupling (Self Sealing)

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Crew discomfort. Imposes unscheduled maintenance on crew.

FAILURE MODE

Fail to operate.

FAILURE CAUSE

Sticking valve, sticking or worn coupling mechanism.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Requires shutdown of element to replace coupling.

** One fault tolerance required.

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT REJECTION - INTERNAL

FMEA No: TC01N-5-3

NOMENCLATURE: Ammonia Interface Heat Exchanger

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Loss experiment, crew discomfort.

FAILURE MODE

Leakage.

FAILURE CAUSE

Corrosion or metal fatigue, micrometeoroid puncture.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Requires EVA to replace. Requires redundant unit or HI with redundant passages.

** One fault tolerance is required.

SYSTEM: THERMAL CONTROL SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGERS
FMEA No: TC03E-5-4.1 NOMENCLATURE: Heat Exchanger

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Increase in cabin temperature.

FAILURE MODE
External leak.
Internal leak.

FAILURE CAUSE
Cracked heat exchanger skin, cracked manifold.
Cracked fin.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Switch to redundant system. ** One fault tolerance is required.

SYSTEM: THERMAL CONTROL SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGER
FMEA No: TC03BD-5-4.3 NOMENCLATURE: Plumbing Assembly FCA

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Crew discomfort due to loss of temp reg Uncontaminated freon external to module.

FAILURE MODE
Leaks.

FAILURE CAUSE
Loose fittings, cracked fittings, cracked lines.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Replace flow control assembly and recharge system. Switch to redundant loop.
** One fault tolerance is required.

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGER

FMEA No: TC03D-5-4.3

NOMENCLATURE: Single Pass Fluid Disconnect

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Loss of temperature regulation of cabin.

FAILURE MODE

Fail to operate.

FAILURE CAUSE

Sticking valve from corrosion, sticking or worn coupling

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Replace flow control assembly. Switch to redundant flow control assembly.

** One fault tolerance is required.

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGER

FMEA No: TC03AA-5-4.4

NOMENCLATURE: Freon 21 Pump

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Increase in cabin temperature.

FAILURE MODE

External leakage.

FAILURE CAUSE

Loose seals, or cracked pump from metal fatigue, corrosion.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant system.

** One fault tolerance is required.

C-3

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGER

FMEA No: TC03AB-5-4.4 NOMENCLATURE: Freon 21 Accumulator

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Increase in cabin temperature.

FAILURE MODE

External leakage.

FAILURE CAUSE

Loose seals, or cracked accumulator due to metal fatigue, corrosion.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant system.

** One fault tolerance is required.

SYSTEM: THERMAL CONTROL

SUBSYSTEM: HEAT REJECTION EXTERNAL EXCHANGER

FMEA No: TC03AC-5-4.4 NOMENCLATURE: Manifold Assembly, Pump Mounting

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:

Increase in cabin temperature.

FAILURE MODE

External leakage.

FAILURE CAUSE

Loose seals, cracked manifold.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Switch to redundant system.

** One fault tolerance is required.

SYSTEM: ECLSS SUBSYSTEM: TEMPERATURE, HUMIDITY & VENT CONTROL
FMEA No: EC01T-7-1.3.1 NOMENCLATURE: Refrigerator

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Limited crew food supply.

FAILURE MODE
Fail to operate.

FAILURE CAUSE
Power bus short or open.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Food transfer between units may be possible. * One fault tolerance is required.

SYSTEM: ECLSS SUBSYSTEM: TEMPERATURE, HUMIDITY & VENT CONTROL
FMEA No: EC01U-7-1.3.2 NOMENCLATURE: Freezer

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Limited crew food supply.

FAILURE MODE
Fail to operate.

FAILURE CAUSE
Power bus open or short.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Limited food transfer between units may be possible. * One fault tolerance is required.

SYSTEM: ECLSS

SUBSYSTEM: ATMOSPHERE CONTROL & SUPPLY

FMEA No: EC15D-7-2.3.2 NOMENCLATURE: Liquid and Gaseous Oxygen Tanks

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Possible change to degraded level of control.

FAILURE MODE

External leakage, restricted flow, fail open.
Loss of or impartial output.

FAILURE CAUSE

High pressure, piece/part failure, inadvertent operation.
Jammed, electrical failure, blockage, part failure, contamination,

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Single tank no redundancy. Loss eliminates backup system for module air makeup but has no immediate impact on cabin survival.
* One fault tolerance is required.

SYSTEM: ECLSS

SUBSYSTEM: EVA SUPPORT

FMEA No: EC11-7-7.1.1 NOMENCLATURE: EMU Service Assembly

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Cancel EVA activity.

FAILURE MODE

Fail to operate.
Fails to open.

FAILURE CAUSE

Loss of power.
Valve failed to open.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)

Not capable of providing oxygen supply required for delivery to EMU, airlock and hyperbaric chamber.
* One fault tolerance is required.

SYSTEM: ECLSS
FMEA No: EC12-7-7.2.1

SUBSYSTEM: EVA SUPPORT
NOMENCLATURE: MMU Service Assembly - N2 Recharge

CRITICALITY ID: 2

HAZARD DESCRIPTION ON S.S./CREW //MISSION:
Restriction on EVA range (No propulsion available.)

FAILURE MODE
Fail to operate.
Fails to open.

FAILURE CAUSE
Loss of power.
Valve fail to open.

WAY(S) OF HAZARD CONTROL: (TWO/ONE FAULT TOLERANCE, COUNTERMEASURE OR ELIMINATION RECOMMENDATION)
Not capable of providing nitrogen supply required for delivery to MMU, as well as airlock and hyperbaric chamber makeup gas.
+++ More from detection method. Sensor data is also used to detect MMU supply level. +++ * One fault
tolerance is required.

6.0 CONCEPTUAL DESIGN

The conceptual design discussed in this section parallels the description of the station found in paragraph 2.4.6. A narrative summary description is found here in.

6.1 Configuration

The Space Station will be a highly capable multipurpose vehicle located in Low Earth Orbit (LEO). It is expected to operate year round for thirty years. The Space Station is to provide:

- A laboratory in space for conducting scientific research and for developing new technologies and related commercial products.
- A permanent observatory for both Earth and stellar viewing.
- A servicing facility where payloads and spacecraft are resupplied, maintained, upgraded and repaired.
- A transportation node where payloads and vehicles are stationed, processed and then propelled to their destinations.
- An assembly facility where large structures are assembled and checked out.
- A manufacturing facility where human resourcefulness and the servicing capability of the Station combine to enhance commercial opportunities in space.
- A storage depot where payloads and parts are kept on orbit for subsequent deployment.
- A staging base for future endeavors in space.

The Station, shown in Figure 6.1-1, and -2, will be an inertially balanced structure in a 28.5 degree, nominal 250 nautical mile altitude Earth orbit adjusted for at-

mospheric variation. The Station will contain an environmentally controlled manned core. The core structure will initially accommodate eight crew and will be located near the Station's center of gravity. The core will consist of six pressurized modules, two resource interconnects, and two airlocks as shown in Figure 6.1-3. The pressurized modules include a U.S. supplied Habitat Module, a U.S. supplied Laboratory Module, A Japanese Experiment Module, a Japanese Experiment Logistics Module, an ESA supplied Laboratory Module, and a U. S. supplied Logistics Module. There will also be a number of unmanned platforms suitable for scientific and commercial activities. One or more of these platforms will be co-orbiting with the manned base. One or more will be in a polar orbit. The platforms will be tended by an Orbital Maneuvering Vehicle (OMV) which will be ground based and fueled, deployed from the NSTS orbiter, and accommodated at the station. Eventually one or more of the OMV's is expected to be kept at the Space Station base.

The Space Shuttle Orbiter will be the primary transportation system for the Space Station. The Orbiter will initially be used to carry the various components aloft and for the assembly and checkout of the Station. After the initial assembly, the Orbiter will transport scientific and commercial payloads to the Station for processing and then return the materials made

6.2 Common Module (Core) Subsystems

The requirements and baseline design Configuration of the Common Module subsystems are covered in Sections 3.1 through 3.9 of Boeing Document D483-50022-2. Rev C (DR-02).

ORIGINAL
OF POOR QUALITY

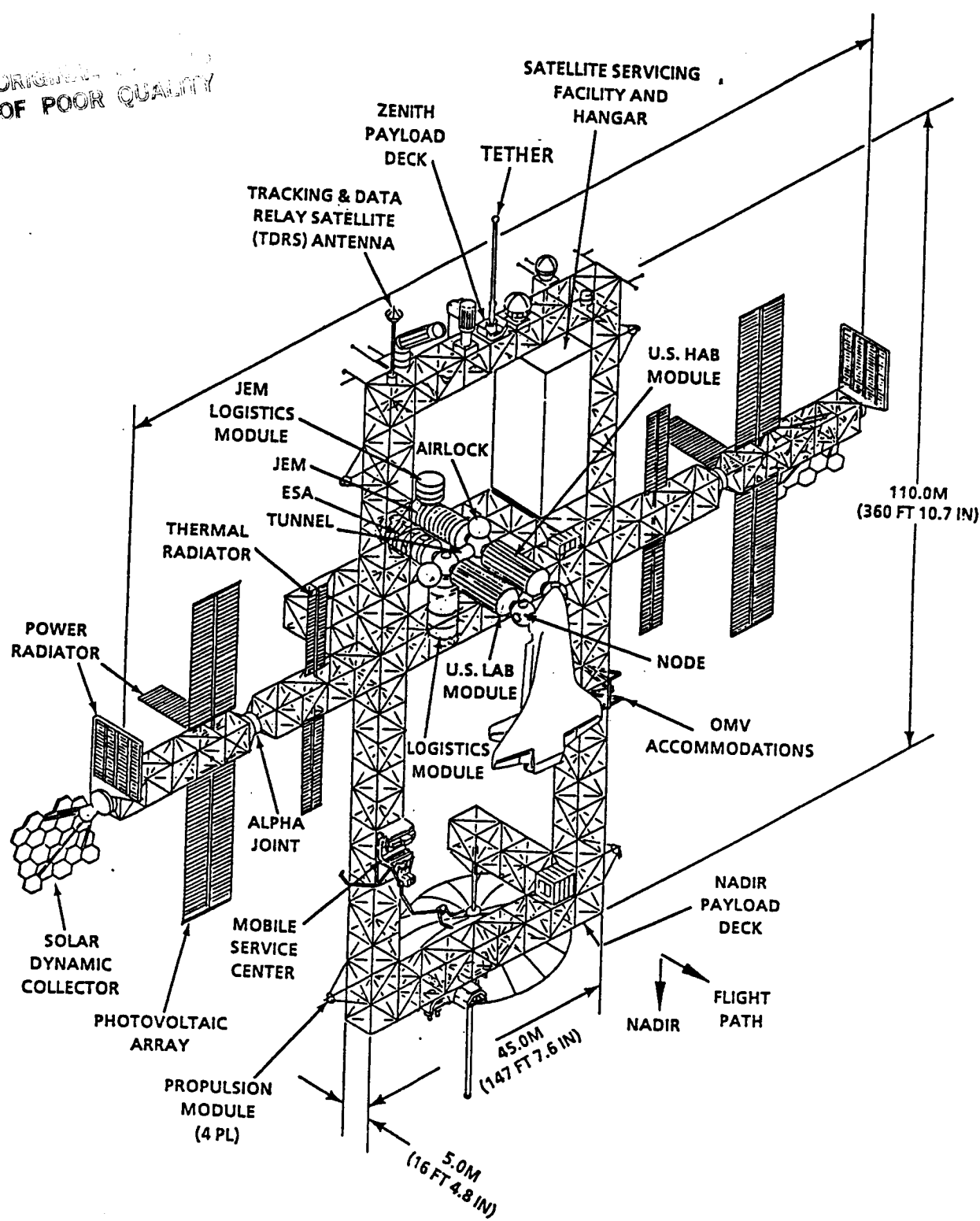


FIGURE 6.1-1 MANNED-CORE SPACE STATION WITH INTERNATIONAL PARTNERS AND TWO U.S. MODULES

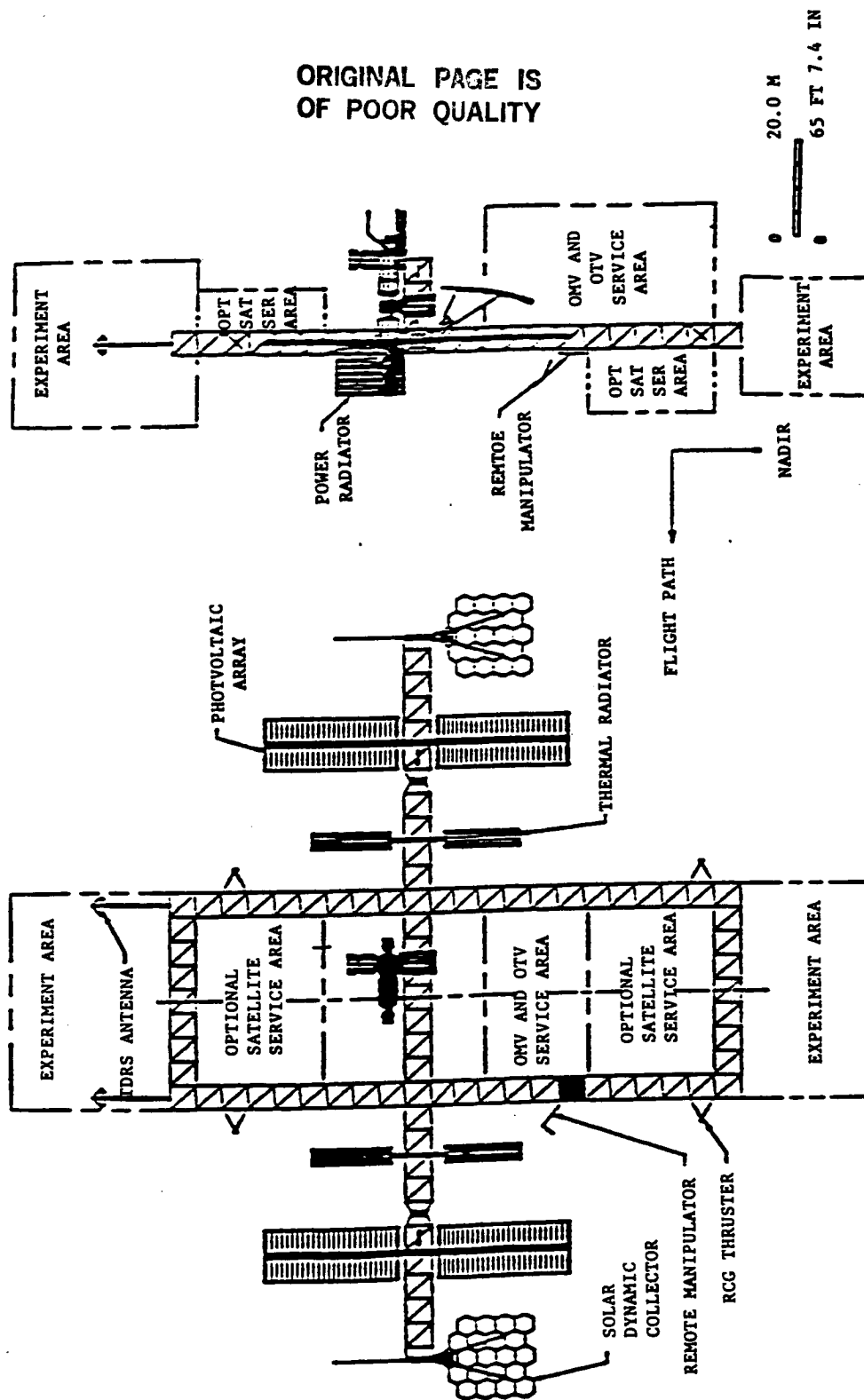


FIGURE 6.1-2 SPACE STATION PAYLOAD ACCOMMODATION

FIGURE 6.1-2 SPACE STATION PAYLOAD ACCOMMODATION

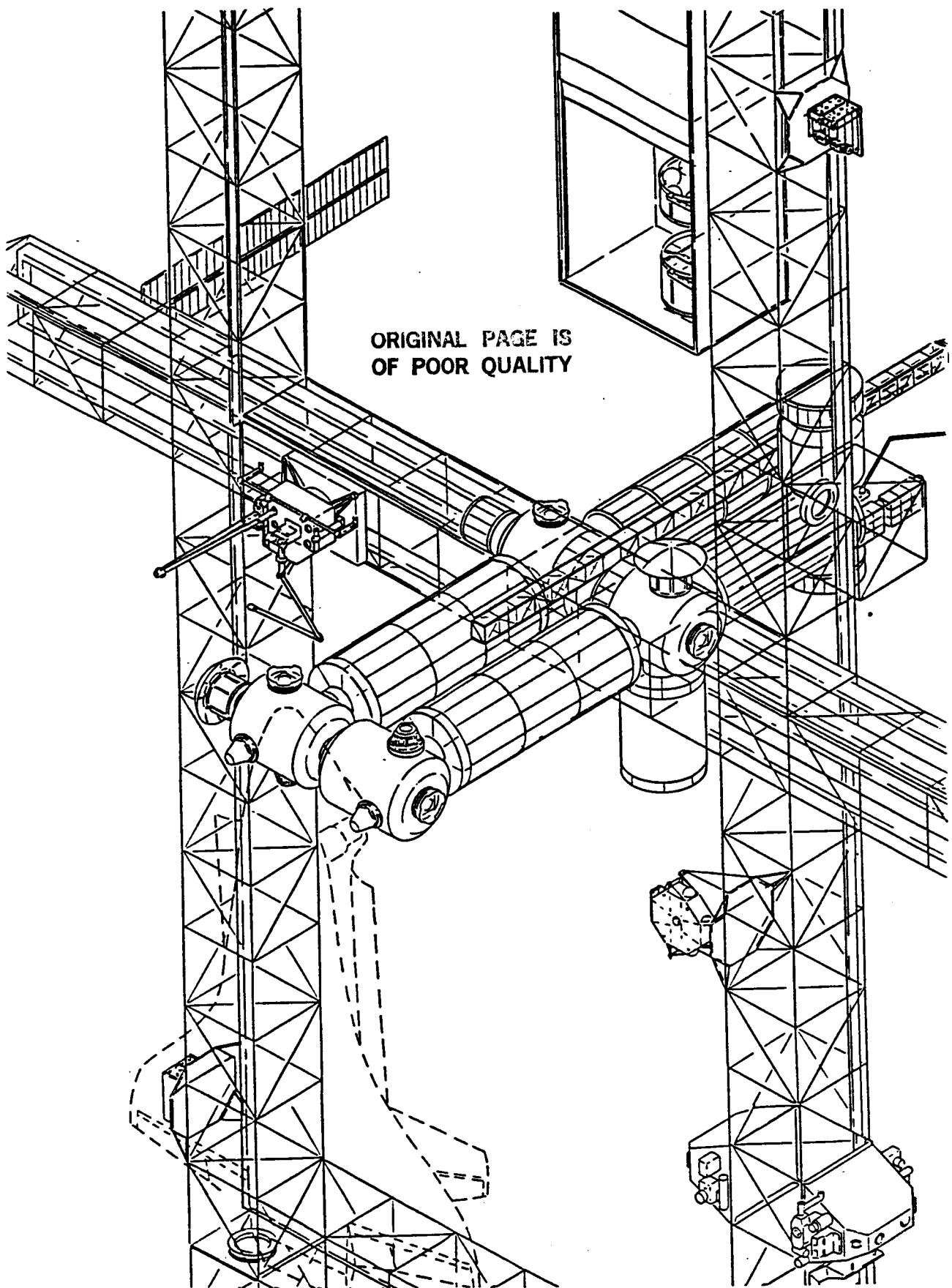


FIGURE 6.1-3 TWO U.S. MODULE PATTERN

6.2.1 Structures and Mechanisms

6.2.1.1 Performance Requirements, General

Total atmospheric leakage from each pressurized module shall not exceed 0.227 Kg (0.5 lbs) per day maximum. As a design goal, leakage shall not exceed 0.045 Kg (0.1 lb) per day.

Berthing ports and hatches shall be sized and shaped by Extravehicular Activity (EVA) requirements, packaging dimensions and hatch thruway limitations. They shall be no less than 1.27 m (50 inches) square with 305 mm (12 inch) radius in the corners.

6.2.1.2 Operational Criteria

a. Service Life Objectives - The Common Module structural system shall be designed for a 30 year life, through periodic inspection, maintenance, replacement of components, reconfiguration on orbit and refurbishment.

(1) Design Approach - The Common Module structural system will be designed to minimize risk and the combined cost of design, development, verification test and launch as a primary objective. Specific steps to be taken to minimize risk and cost will include the following:

Design to resist yielding or buckling at 2.05 times the required static test loads and avoid the cost of a dedicated test article.

(2) Maximum Weight Launch :

18,595 kg (41,000 lb.)

(3) Maximum landing Weight :

12,780 kg (28,000 lb.)

(4) Abort Landing :

18,595 kg (41,000 lb.)

b. Environmental Criteria

(1) Natural Environment - The following natural environmental criteria per JSC 04400 Vol. XIV and JSC 30000 will be considered in the design of equipment.

c. Applied Loads Criteria - Applied loads shall not exceed design limit loads criteria for the Common Module, nor shall they exceed the allowable interface loads specified for integrated shuttle cargo bay and Space Station configurations.

d. Pressurization - The pressurization requirements criteria presented here shall apply to all modules or portions of modules, compartments and interconnection elements to be pressurized and manned on orbit.

(1) Launch and On Orbit - Internal pressures will be maintained at 101.36 + 3.45kPa (14.7 + 0.5 psia) during launch and delivery to orbit.

e. Structural Dynamics Criteria

(1) Loads - Dynamic loads shall not exceed design limit loads criteria for the Common Module, nor shall they exceed the allowable interface loads specified for integrated shuttle cargo bay and Space Station configurations.

Common Module component dynamic characteristics shall be compatible with the integrated Space Station dynamics and shall not contribute to any Space Station instabilities or degradation below required criteria for controllability, energy management, and mission performance.

Dynamic responses (including frequencies, mode shapes, damping, transmissibility, displacements, velocities, and accelerations) shall not exceed specified criteria or other acceptable characteristics for crew efficiency, crew comfort, and system performance. Responses in the integrated STS transport and Space Station configurations shall not exceed allowable interface envelopes.

- (2) Verification - Verification of acceptable dynamic responses and resultant loads shall be accomplished by appropriate methods of structural dynamic analyses and subsequent test programs aimed at verifying methods and measuring response to known excitations. Both component and integrated analyses and tests shall be utilized where feasible to improve level of confidence. Types of testing to consider shall include static influence coefficient tests, Ground Vibration Test (GVT), acoustic chamber testing, and shuttle flight testing in cargo bay configuration. Experiences of similar shuttle payload verification programs such as IUS will be utilized

in the development of the Common Module verification plan.

- (3) Success Criteria - The primary measure of success will be verification of analytical predictions of modes, and responses under 1g Earth atmosphere conditions. Subsequent test correlations and analysis refinements will be used to verify that results meet criteria and requirements specified. Use of test bed programs, trade studies, and accumulated space operational experience will be required to establish appropriate criteria in unproven areas. Extension or extrapolation to space environment will be attempted where data and methods permit. Integrated shuttle cargo bay loads and responses must meet ICD 2-19001 Shuttle Orbiter/Cargo Standard Interface requirements.

- f. Drive Mechanisms Criteria TBD
- g. Structural Temperature Criteria 70°F
- h. Electromagnetic Compatibility and Interference Criteria per MIL-STD-461B.
- i. Materials and Processes Criteria per JSC document 20149, MSFC-SPEC-522A.
- j. Structural Allowable Criteria MSFC per- HDBK-505A.

6.2.2 Baseline Structural Description

The basic structural concept is an all-welded pressure shell with internal pay-

load support structure, using an external shield and multi-layer insulation for meteoroid and debris protection. Structural requirements are listed in Table 6.2.2-I. A Common Module weight statement is included in Table 6.2.2-II.

6.2.2.1 Primary Structure

The pressure shell is a 45° waffle stiffened, welded aluminum alloy 2219 structure with conical bulkheads. The overall structural arrangement is shown in Figure 6.2.2.1-1.

The shell has a pressure carrying skin which is .32cm (.125 in) thick. The ribs are .23cm (.09 in) thick and 2.22cm (.875 in) high. They are optimally spaced to carry the appropriate loadings. The shell panels are rolled before welding into a 90° segment of the skin. Four of the 90° segments are welded longitudinally to form a cylindrical section.

Primary rings made from roll forgings are welded integrally into the pressure shell. Two of the primary rings form the junction at the bulkhead-to-shell joint. The primary rings have external flanges that provide attachment points for thermal and meteoroid protection panels and payload support structure.

Trunnion and keel pin fittings for attaching the module within the orbiter payload bay are located on primary rings as shown in Figure 6.2.2.1-1. Designs of the trunnion and keelpin assemblies are shown in Figures 6.2.2.1-2 through 6.2.2.1-4.

The module has two berthing ports, at opposite ends on each conical bulkhead. Each port has an inward opening closure hatch. The opening is 1.3M (50 inches) square with 0.3M (12 inches) corner radius. The berthing ring is shown in Figure 6.2.2.1-5. The hatch design is shown in Figures 6.2.2.1-6 through 6.2.2.1-8.

The Common Module window, shown in Figure 6.2.2.1-9, consists of three panes of glass, attachment rings, and seals. The outer pane assembly consists of a redundant pane and a pane for meteoroid protection. An inner assembly consists of the primary pane.

The window panes will be limited to minimal light degradation of 65 percent of the total range, 400 to 700nm after infrared, ultraviolet, and antireflection coating. The sealing material will be RTV 566. The meteoroid protection and the redundant pane assembly will be removed and replaced by EVA. The primary pane assembly will be removed and replaced by IVA. Both the primary and redundant panes will withstand the internal pressure loads individually.

6.2.2.2 Meteoroid/Debris Radiation Protection

The meteoroid, debris, and radiation protection subsystem shown in Figure 6.2.2.2-1 combines functional elements of the thermal protection and structural subsystems. The 3.18mm (0.125 in.) pressure shell, 30 layers of multi-layer insulation, and 1.0mm (0.04 in.) aluminum shields protect the cylindrical portions of the module from meteoroids, debris, and radiation. The structural design provides a 114.3mm (4.5 in) standoff distance between the shield and pressure shell.

6.2.2.3 Payload Support Structure

The internal payload support structure, common for the floor and ceiling, provides positioning, attachment, and support function for equipment racks, housekeeping equipment, utility services, and the subsystem packages. The floor and ceiling structure are identical and are composed of two 90° support beams. These beams are supported by brackets which are

TABLE 6.2-I A COMMON MODULE STRUCTURAL REQUIREMENTS

I Factors of safety

A. Design ultimate pressure

1. Shell = $2.67 \times \text{max expected operating pressure (MEOP)}$ (15.2)
2. Windows, doors, hatches = $3.00 \times \text{MEOP}$

B. Design yield pressure = $2.20 \times \text{MEOP}$

C. Proof test pressure = $2.00 \times \text{MEOP}$

II Fracture mechanics criteria

A. Leak before rupture/no leak (fail safe/safe life)

III Damage tolerance

A. 95% probability of no shell penetration in 10 years

B. Catastrophic failure at limit load would not occur as a result of the loss of any single ring or stiffener and adjacent skin

IV Cycles and life

A. 1,000 pressure cycles minimum \times factor of 4 on life = 4,000

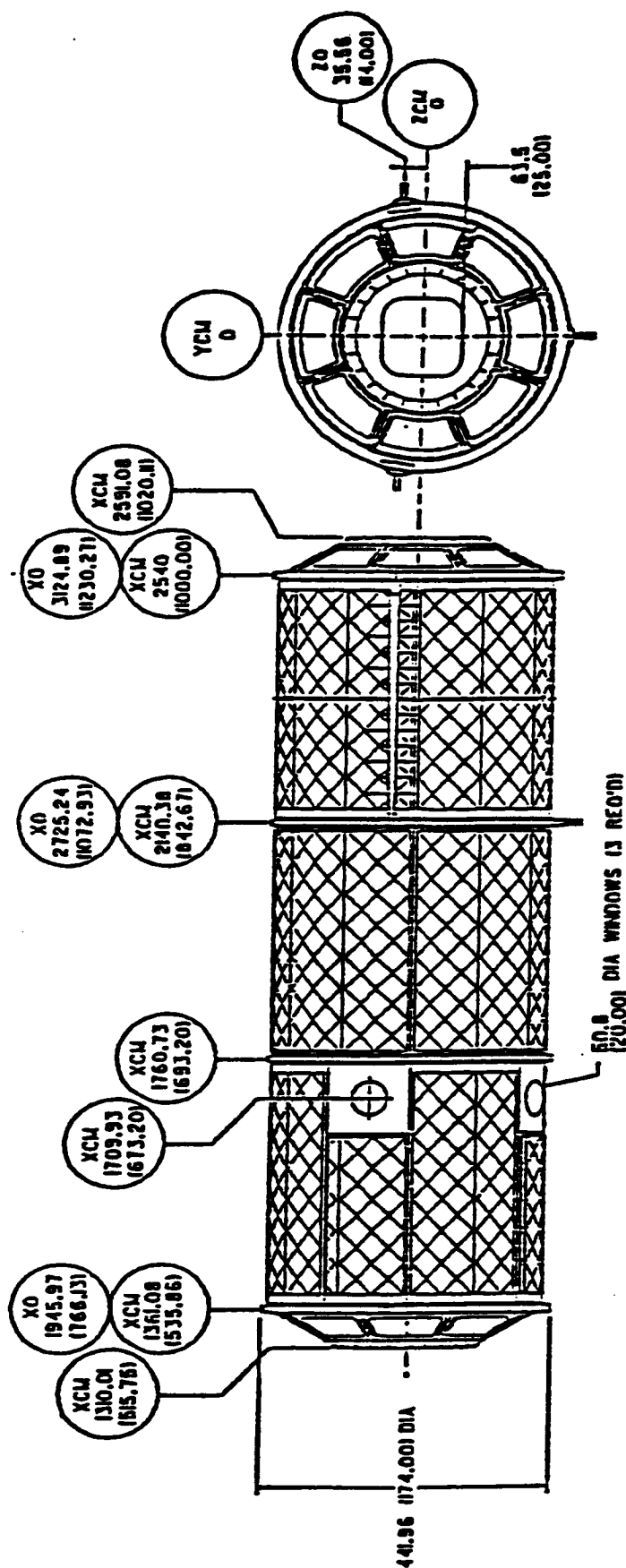
B. 10-year service life

V Launch loads, abort landing, orbital return, docking loads

VII Stiffness, acoustic response

TABLE 6.2.2-II COMMON MODULE WEIGHT STATEMENT

CYLINDER LENGTH 8.88 METERS (29.1 FEET)	MASS PER BASELINE MODULE	
	KG	(LB)
ITEM		
PRESSURE SHELL - CYLINDER	1678	(3699)
PRESSURE SHELL - BULKHEAD (30°)	285	(628)
RING FRAMES (4)	539	(1188)
KEEL & SIDE TRUNNIONS & SUPPORT	139	(306)
GRAPPLE & SUPPORTS	19	(42)
HATCHES, RINGS & MECHANISM (2)	675	(1488)
WINDOW (3) - (INCL. CLOSEOUT PLATE 52.8" X 42.1")	306	(675)
DEBRIS SHIELD & SUPPORTS	919	(2025)
4 STANDOFF STRUCTURE & CABLE TRAYS	1116	(2461)
STABILITY RING (1)	15	(33)
EQUIPMENT RACKS - GENERAL (16)	1357	(2992)
IVA & EVA HANDRAILS & FOOT RESTRAINT	112	(247)
RIGID BERTHING MECHANISMS (2)	272	(600)
TOTAL	7432	(16384)

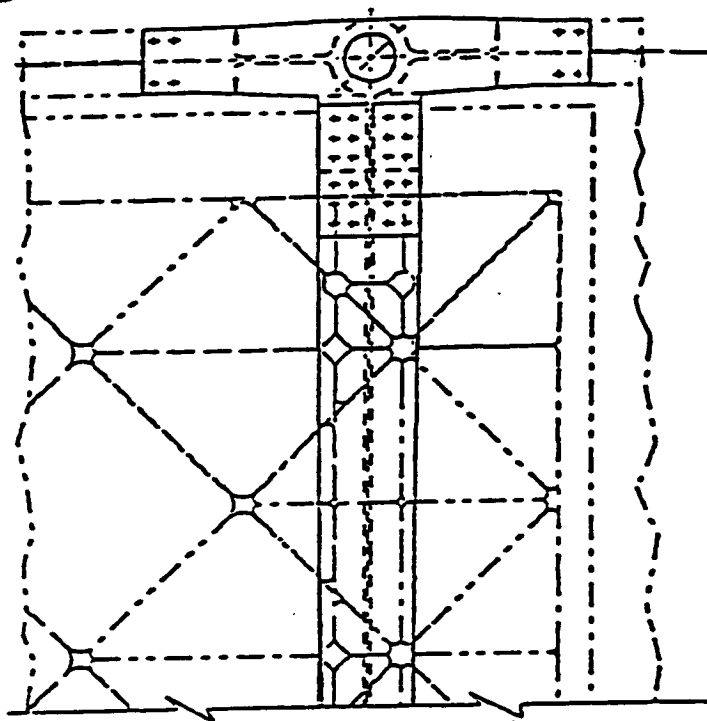


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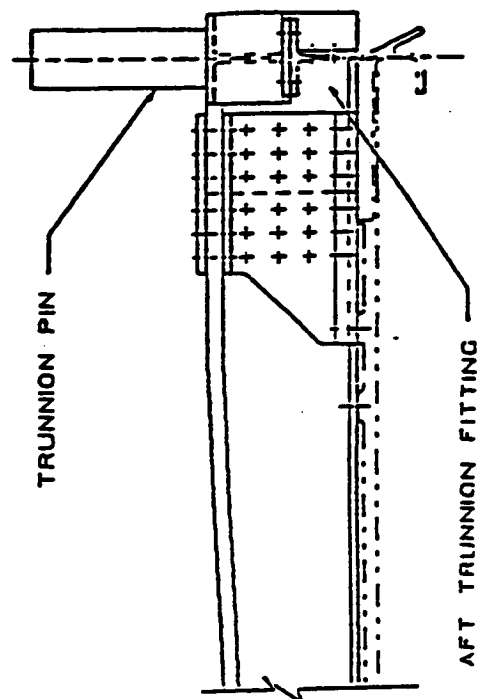
NOTE: ALL DIMENSIONS IN CM (INCHES)
METEOROID SHIELD NOT SHOWN

FIGURE 6.2.2.1-1 COMMON MODULE STRUCTURAL ARRANGEMENTS

FIGURE 6.2.2.1-1 COMMON MODULE STRUCTURAL ARRANGEMENTS

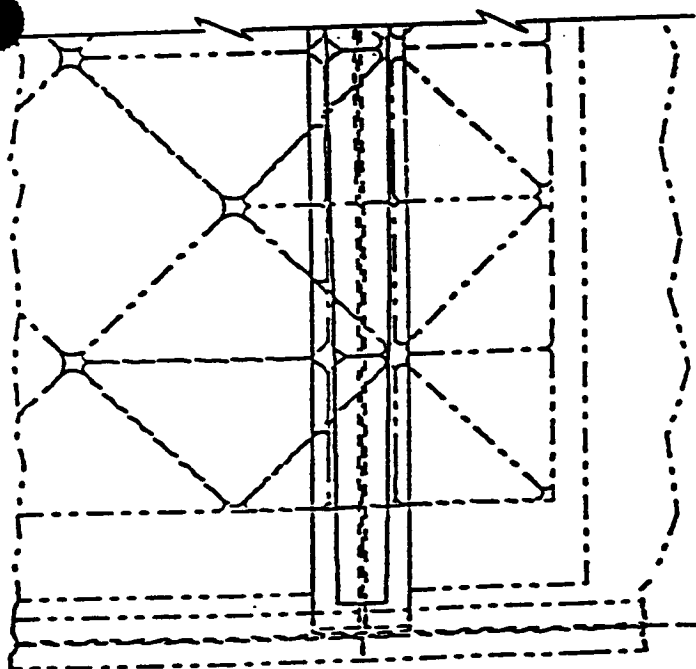


Xo 3124.89 (1230.27)
Xom 2540 (1000.00)

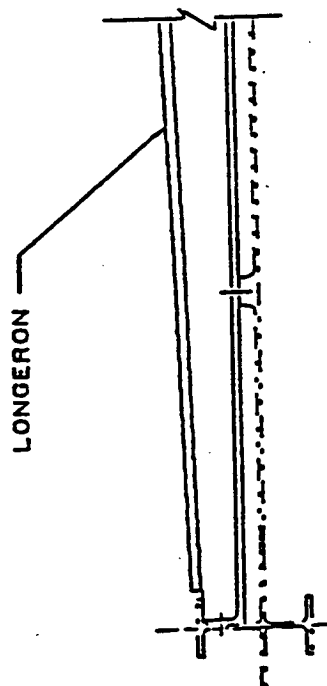


TRUNNION PIN

AFT TRUNNION FITTING



Xo 2725.24 (1072.93)
Xom 2140.38 (842.67)



LONGERON

FIGURE 6.2.2.1-2 TRUNNION AND KEEL PIN ASSEMBLIES

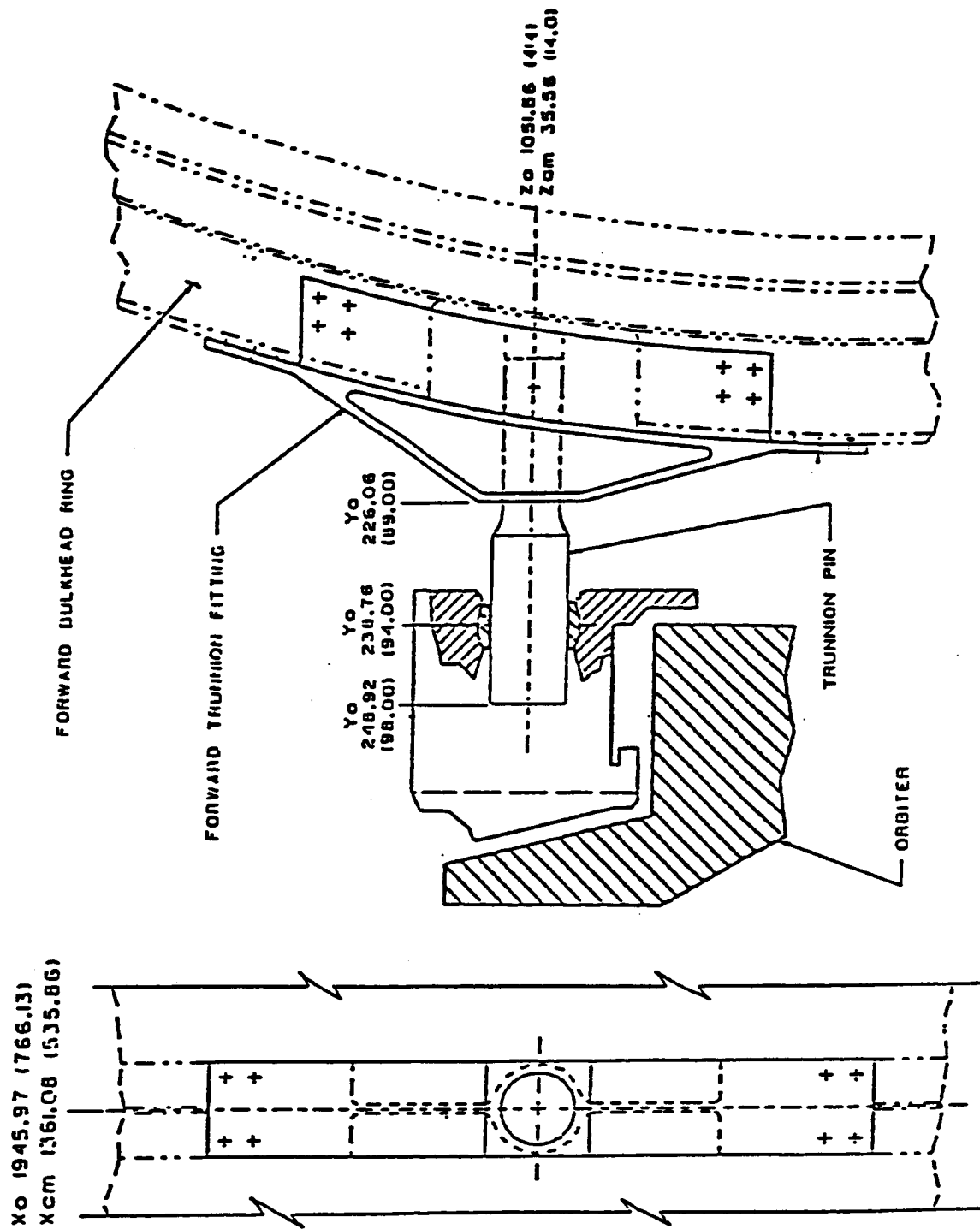


FIGURE 6.2.2.1-3 TRUNNION AND KEEL PIN ASSEMBLIES

FIGURE 6.2.2.1-3 TRUNNION AND KEEL PIN ASSEMBLIES

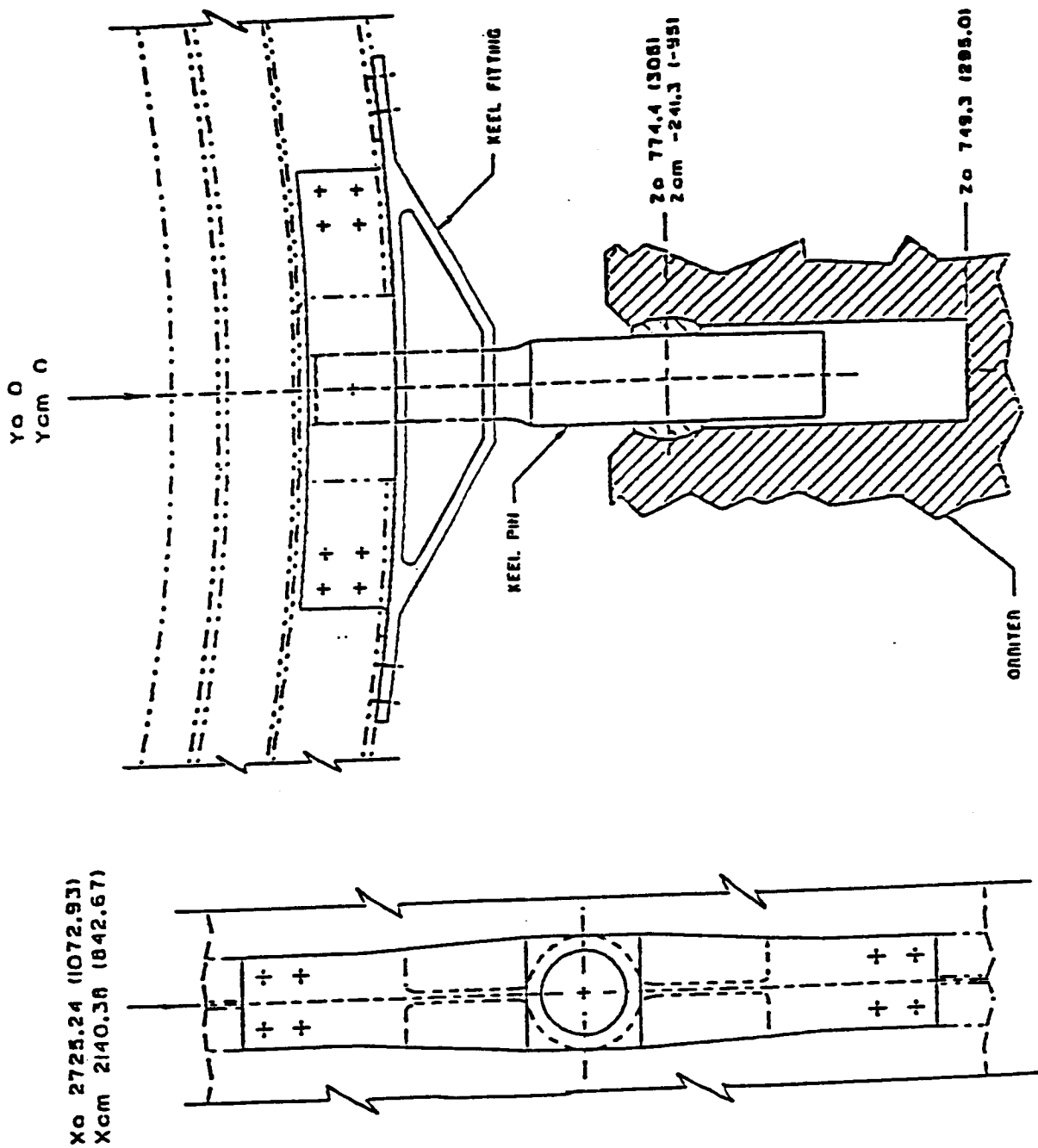
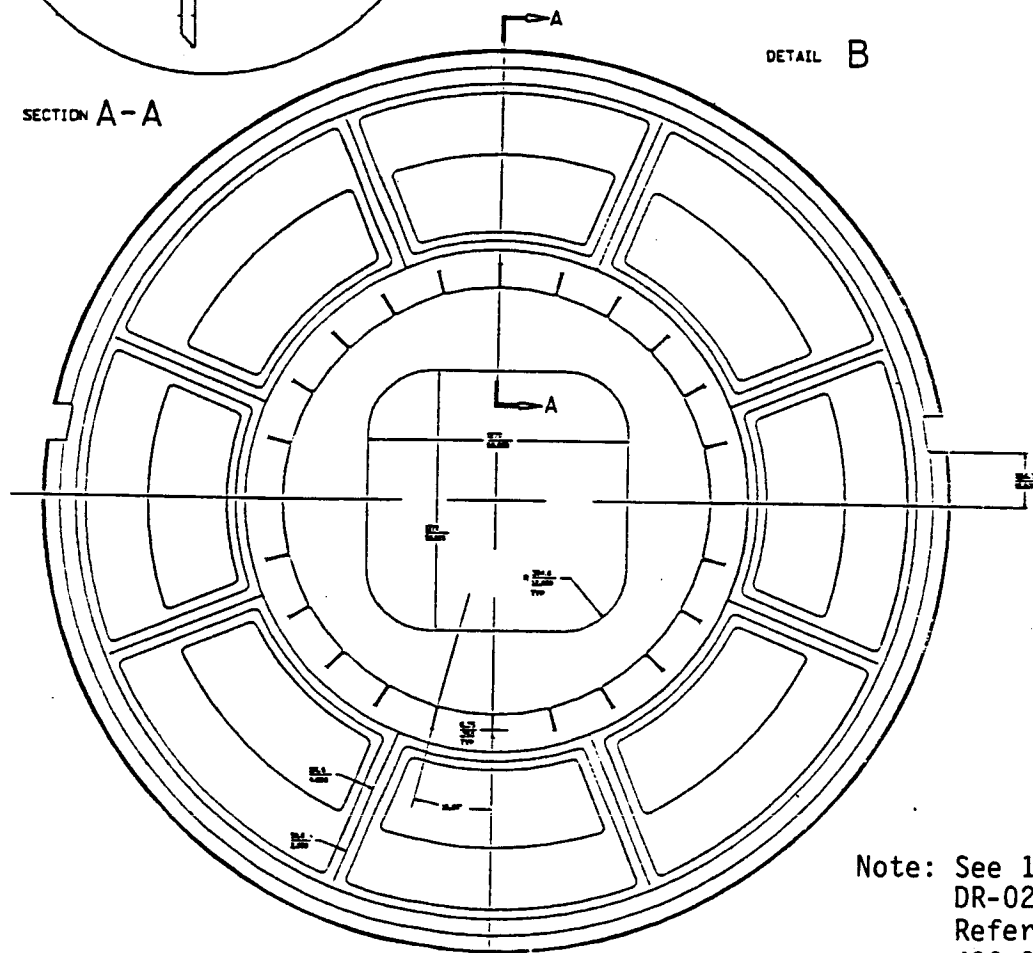
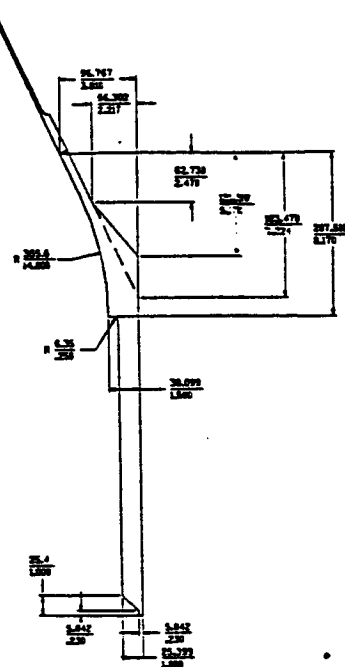
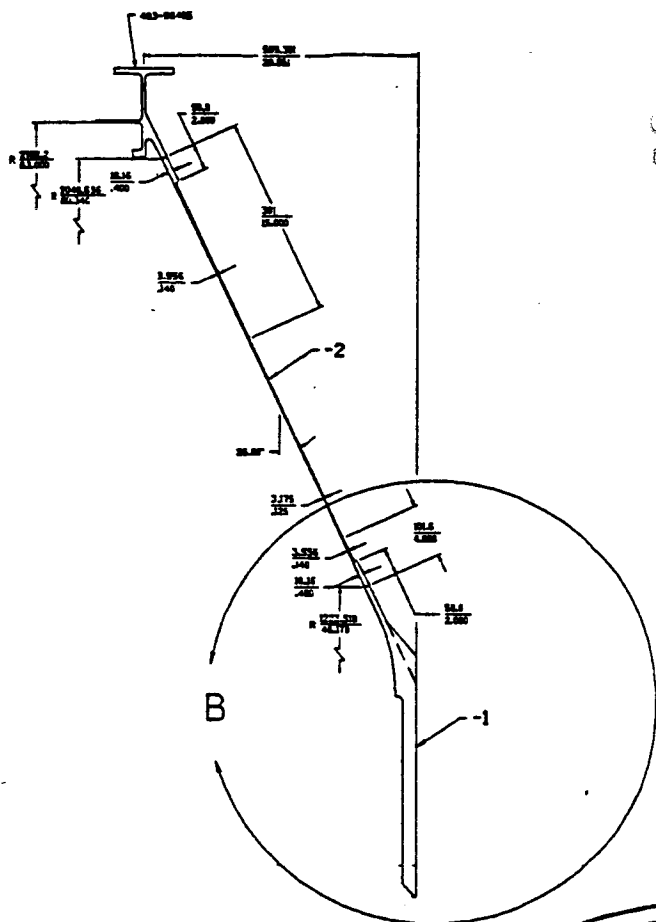


FIGURE 6.2.2.1-4 TRUNNION AND KEEL PIN ASSEMBLIES

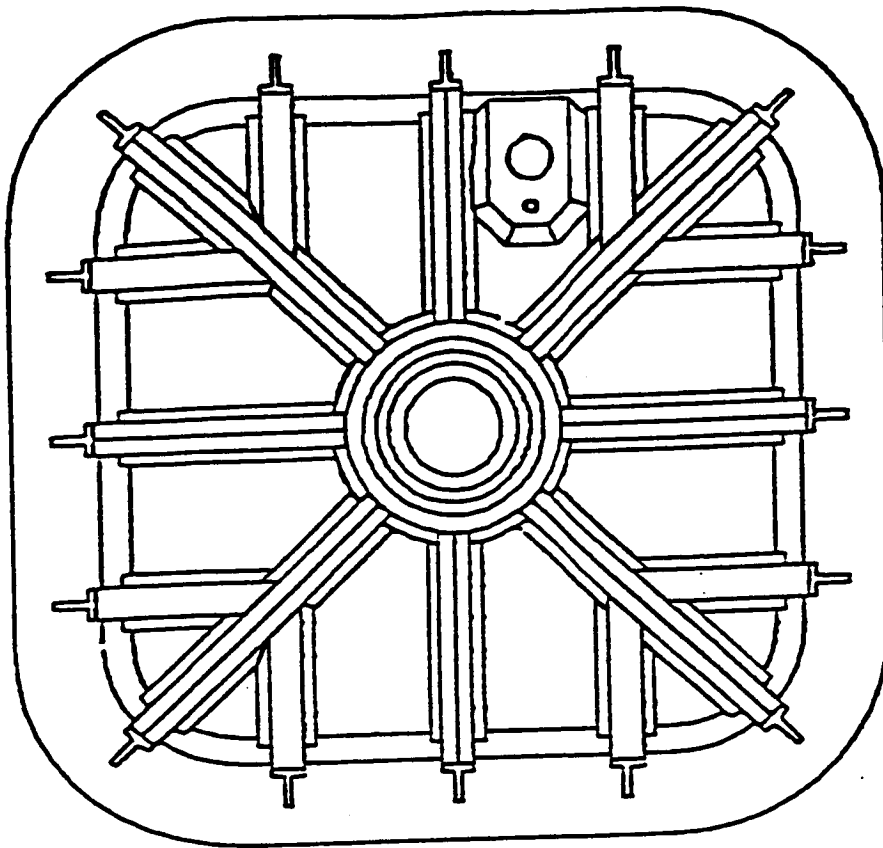
FIGURE 6.2.2.1-4 TRUNNION AND KEEL PIN ASSEMBLIES

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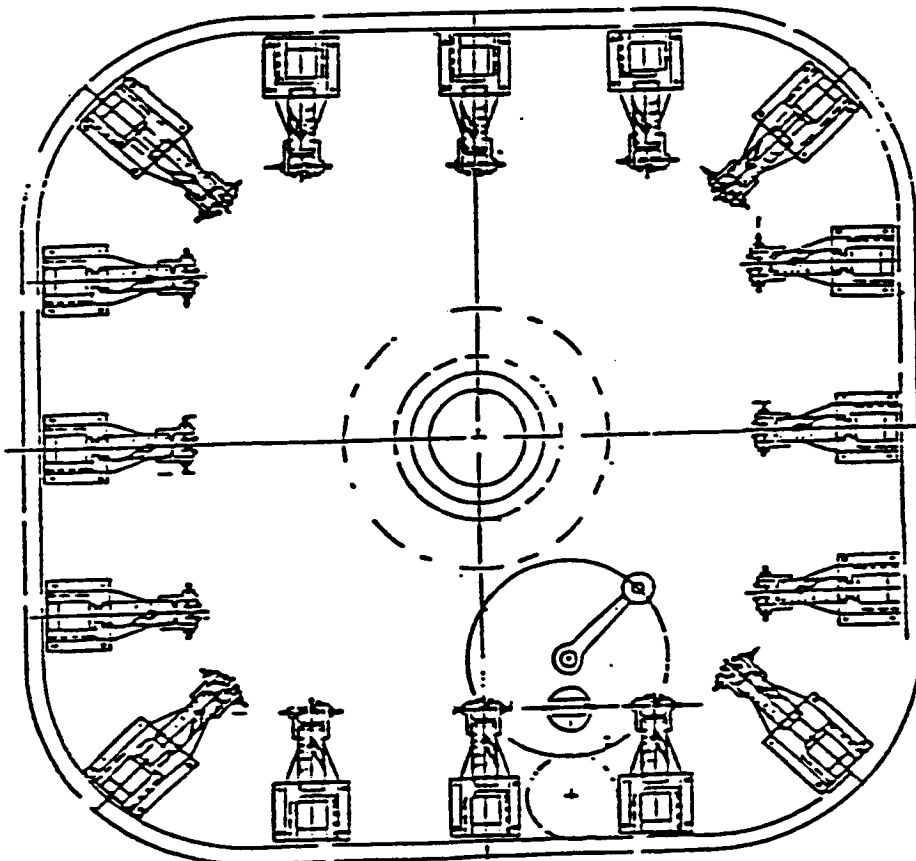


Note: See 18 January 1987
DR-02 Submittal for
Reference Layout No.
483-96404

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INBOARD



OUTBOARD

FIGURE 6.2.2.1-6 HATCH DESIGN

FIGURE 6.2.2.1-6 HATCH DESIGN

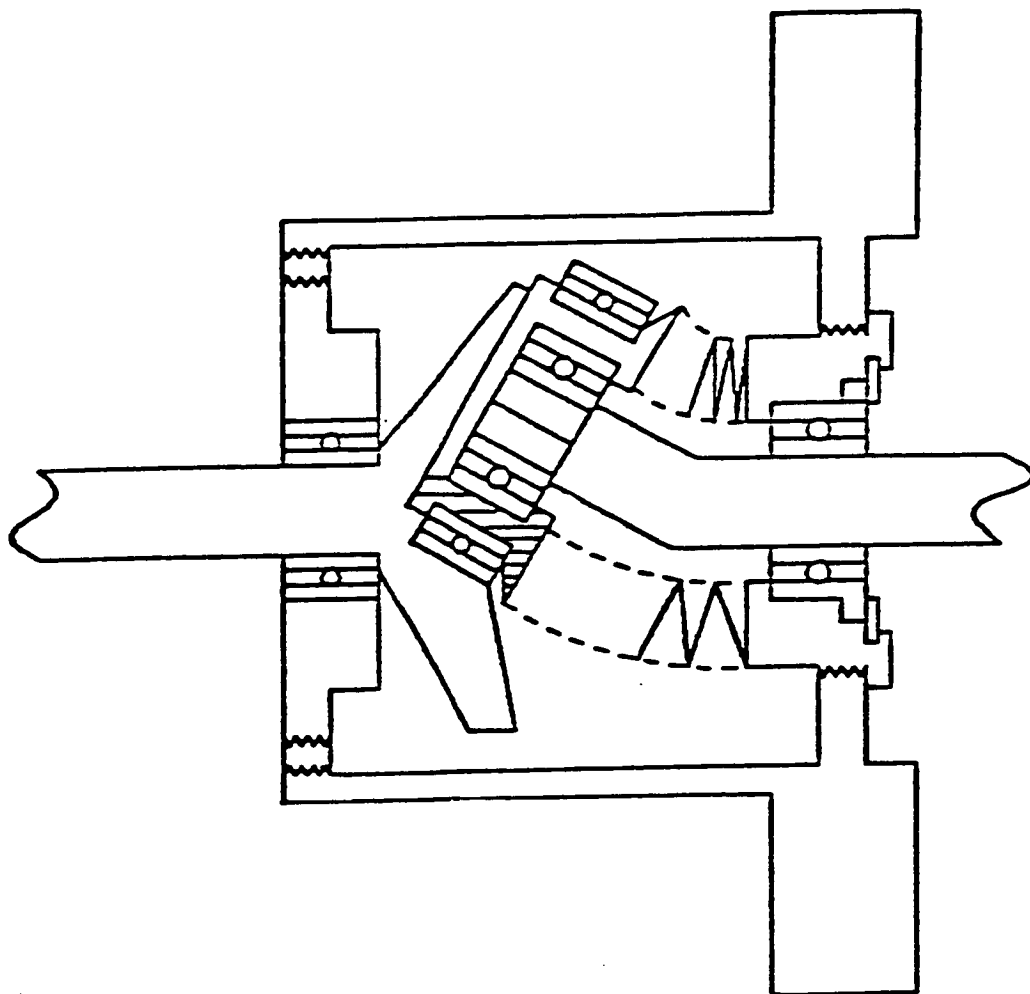


FIGURE 6.2.2.1-7 ROTARY FEED THROUGH MECHANISM

FIGURE 6.2.2.1-7 ROTARY FEED THROUGH MECHANISM

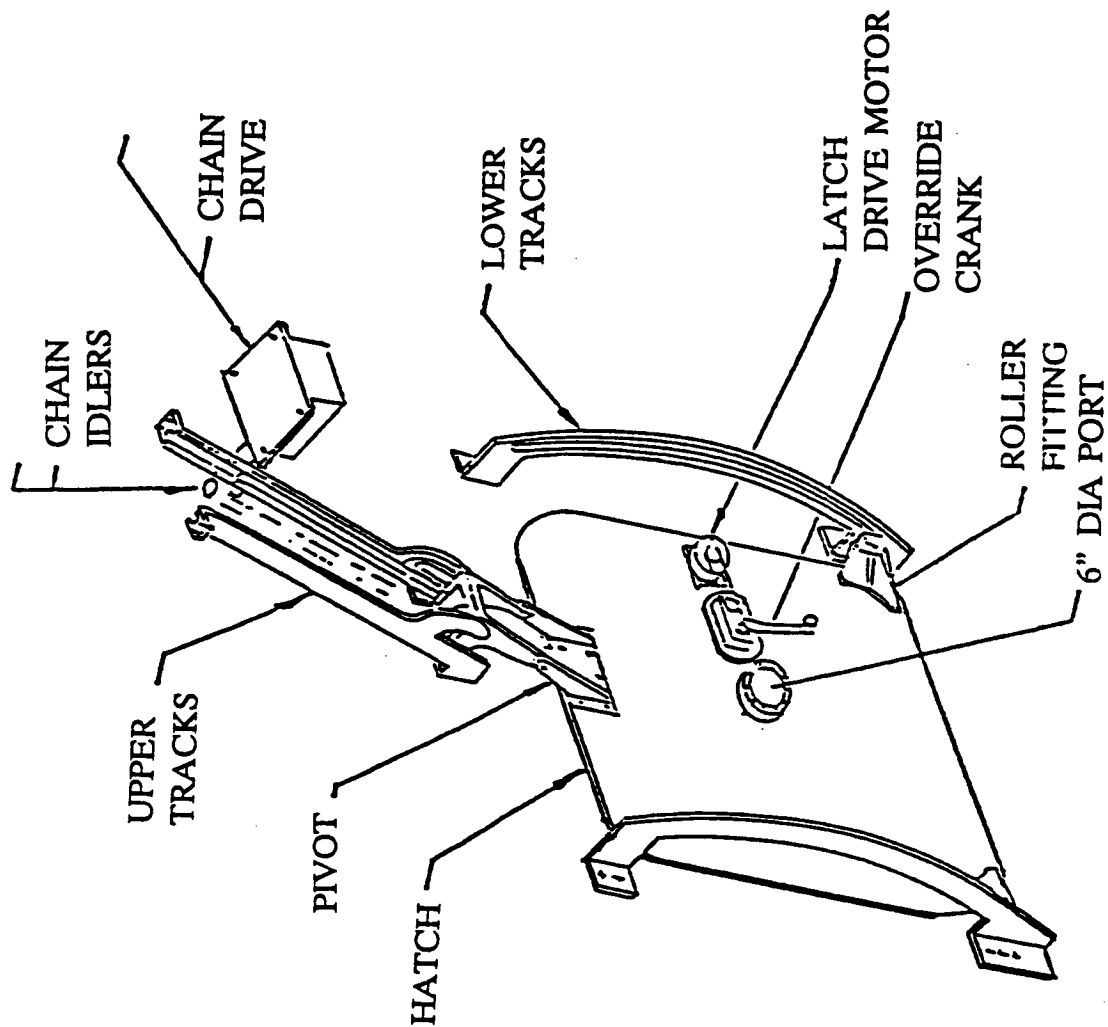


FIGURE 6.2.2.1-8 HATCH DESIGN

FIGURE 6.2.2.1-8 HATCH DESIGN

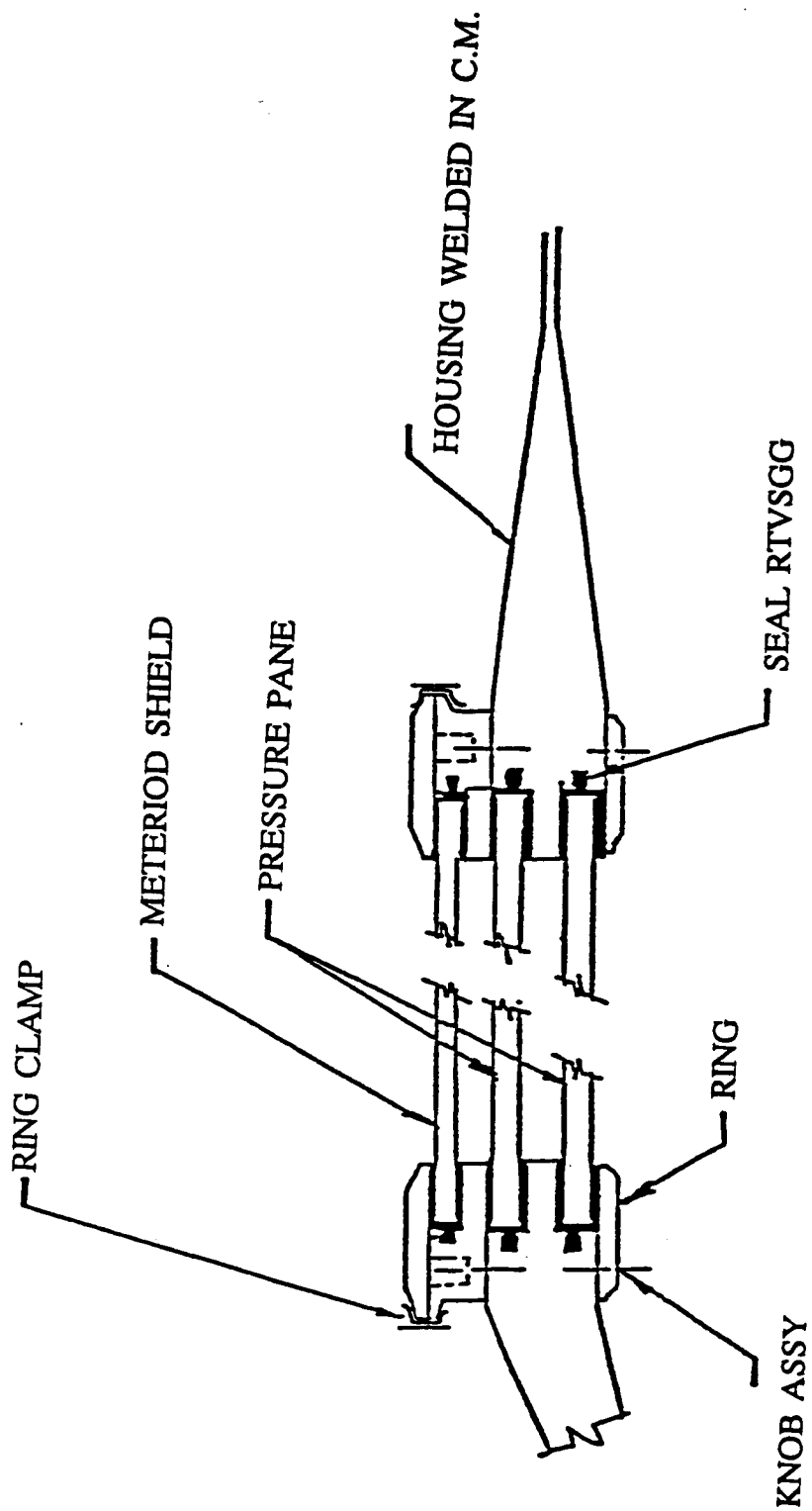


FIGURE 6.2.2.1-9 COMMON MODULE WINDOW

FIGURE 6.2.2.1-9 COMMON MODULE WINDOW

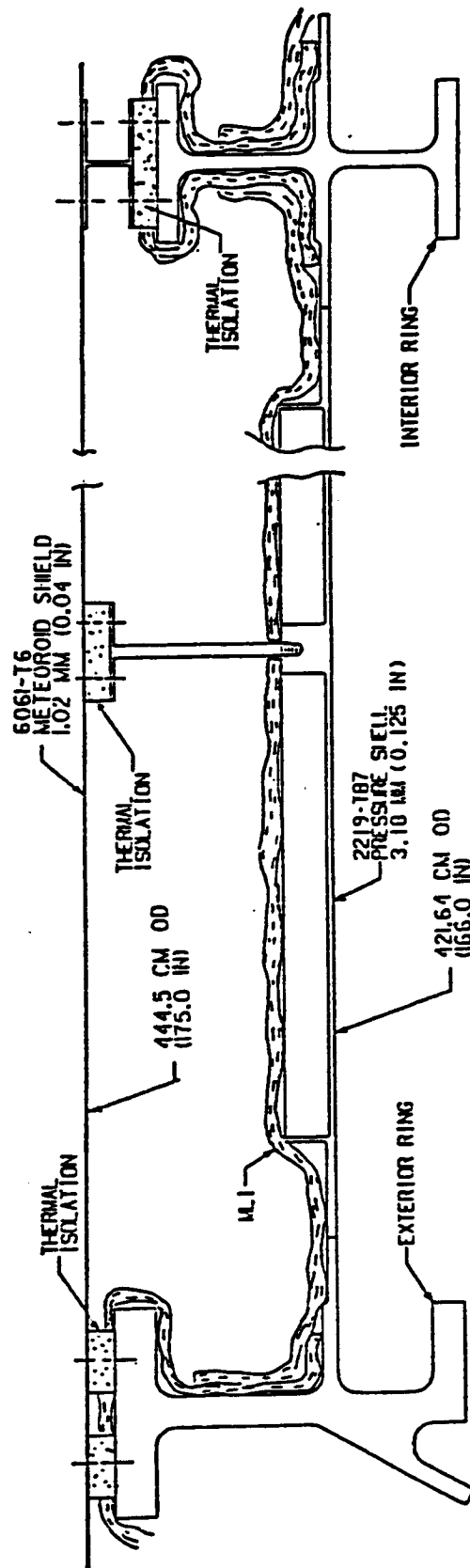


FIGURE 6.2.2.2-1 METEOROID/DEBRIS, RADIATION AND THERMAL PROTECTION

attached to the primary pressure shell. The structure is flexible to accommodate different payload arrangements. The support structure is shown in Figure 6.2.2.3-1. The equipment racks will consist of single and double wide (528.4mm) (20.8 in) and 1066.8mm (42.0 in) slide mounted racks that conform to the envelope shown in Figure 6.2.2.3-2. The basic structure and attach mechanisms will be common. However, the racks can be tailored using optional add on parts to meet any specific requirements imposed by the subsystem or payload being housed. Utilities will be front attached.

Conventional riveted construction with aluminum alloy 7075-T73 is the baseline, but composites are in consideration due to their weight advantage.

6.2.3 Electrical Power Subsystem

6.2.3.1 Power System Design

The Electric Power Distribution System (EPDS) discussed in the following paragraphs represents the design synthesized by Boeing, Martin-Marietta, and Marshall Space Flight Center.

6.2.3.1.1 General

The concept of a Common Module is to establish a basic unit that can, by simple modifications, be configured for all Space Station activities requiring "shirt sleeve" environment. This approach fosters simplified maintenance and low life cycle cost through similarity of layouts and commonality of housekeeping and resource units. Since electric power is one of the basic resources, commonality and versatility are primary considerations.

6.2.3.1.2 Primary Power Interface

This discussion considers the interface between the Common Module (WP-01) and

the Power Generation and Storage System (WP-04) as all electric power items mounted on the Space Station structure. These items are part of and will be controlled by WP-04. All electric power items mounted on the Common Module are part of and will be controlled by WP-01. Thus the transmission lines, main power switching unit and feeders, all external to the Common Module are WP-04 responsibilities.

Each Common Module EPDS receives primary power at two (redundant) penetrators from the Power Generation and Storage System. These penetrators are separated as far apart as practical in order to minimize the potential that any one accidental event will damage both sources of power to the Common Module.

IOC primary power will provide 87.5kW of 440 volts, single phase, at 20K Hz. As discussed later, a transformer attached to the outside of the penetrator will provide electrical isolation for each Common Module and reduce the voltage internal to the Common Module to 208 V., single phase, 20K Hz.

The transformers, penetrators, and feeders will be protected from overload by remote bus isolators in the Main. Bus Switching Assembly. The transformers, penetrators, and feeders shall be isolated for maintenance by a manually operated circuit isolator in the Main Bus Switching Assembly.

The transformers, penetrators, and feeders shall be designed for 50 kW capability.

The quality of the power from the Power Generation system has not yet been defined. Voltage regulation and response to transients is of great concern. Until further information is obtained the qualities of the 20K Hz single-Phase source, as in MIL-STD-7040 will be used.

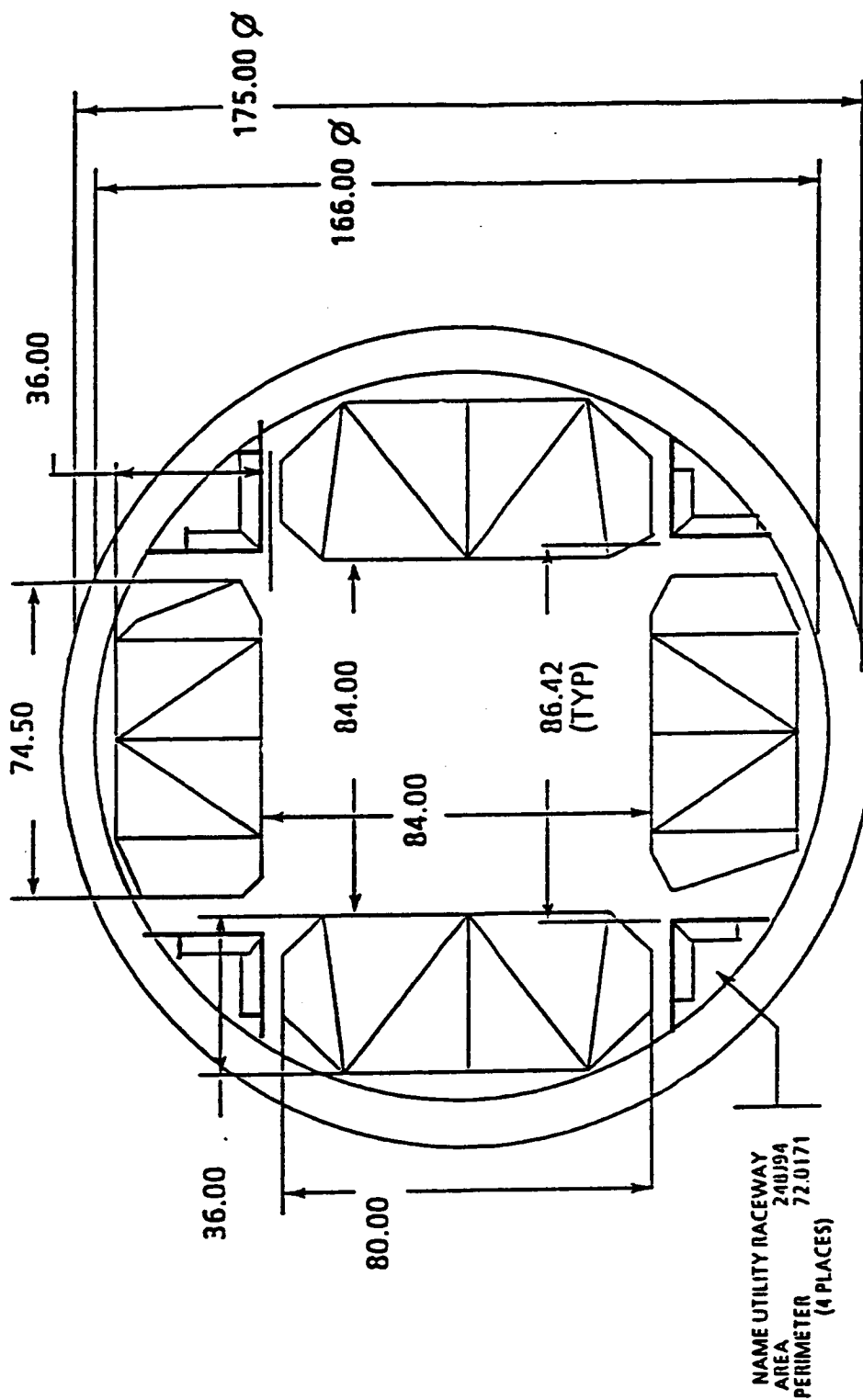
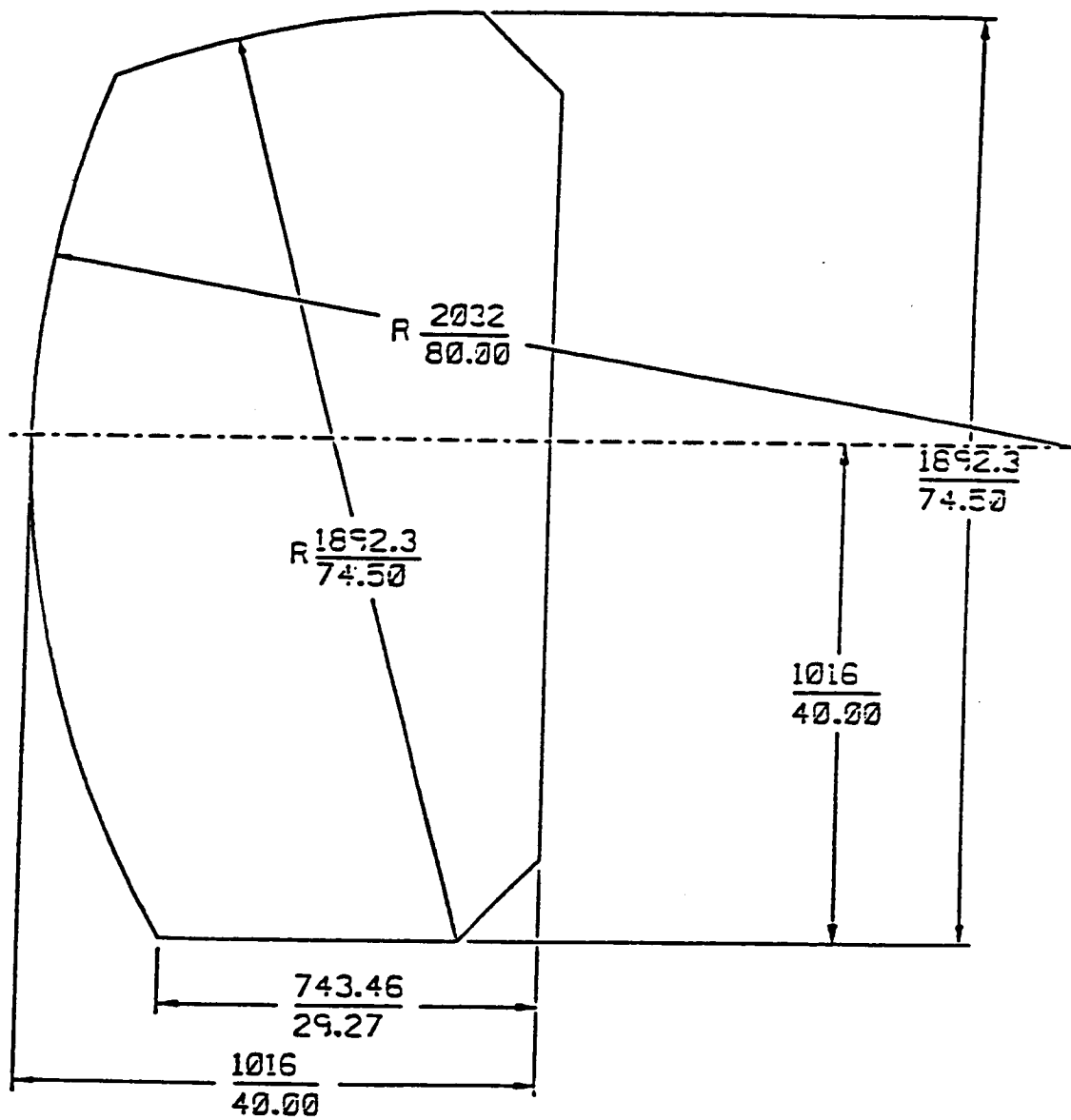


FIGURE 6.2.2.3-1 COMMON MODULE PAYLOAD STRUCTURE

FIGURE 6.2.2.3-1 COMMON MODULE PAYLOAD STRUCTURE



NOTE: ALL DIMENSIONS IN MM/IN

FIGURE 6.2.2.3-2 RACK ENVELOPE

6.2.3.1.3 Secondary Power

There are indications that certain users desire power types other than the utility power of 208V, single phase, 20K Hz. In general the conversion to the desired power type is to be included in the user rack. The converter may be supplied by the outfitter (NASA) or the user. If there is sufficient demand for a particular power type a large converter will be installed with that power type distributed to a limited number of racks.

6.2.3.1.4 Safehaven

All electrical loads in the Common Module are controlled by the autonomous control system through circuit breakers and switches. The autonomous control system schedules loads in accordance with predetermined priorities and available power. Under safe haven conditions the autonomous control system sheds loads in accordance with the predetermined schedule to meet the available power.

6.2.3.1.5 Safety and Fault Tolerance

The utility power to be distributed in the Common Module is 208V single phase 20K Hz. This voltage is considered lethal. As a consequence, the EPDS shall be designed to prevent, to the greatest extent practical, the exposure of the Space Station personnel to the utility voltage. All utility power receptacles shall be dead faced and/or interlocked to prevent switching of power to the receptacle without a cable/load being attached. Also each receptacle shall have overload protection which will automatically disconnect the power from the receptacle should the current exceed a predetermined safe value. Each circuit shall also be protected by a ground fault isolator.

Each subsystem and load shall adhere to the single point ground guidelines and be

designed to meet the requirements of a bonding specification of MIL-B-5087B.

Each cabinet containing components of the EPDS shall be dead-front and dead-face when opened for maintenance of Orbital Replacement Units (ORUs). A means of disconnect and lock-out to isolate each circuit for maintenance or repair shall be provided.

The lock-out method shall provide a readily visible mechanical signal to indicate that the circuit is isolated and safe to work on.

Noncritical loads shall be fail-safe/restorable. In general this means that in the event of a failure, such as the loss of power, the load will not present a hazard to the Space Station or personnel. A failure in the power distribution that resulted in the loss of power to a load shall be restorable by replacement of an ORU. If the load requires a soft shutdown in order to store toxic materials or prevent a fire it must supply the soft shutdown capability or arrange for redundant power connection for that purpose.

Critical loads shall be fail operational/fail safe/restorable. In general fail operational means that in the event of a failure, such as the loss of power, a redundant power connection shall be provided to maintain the function of the critical load. In order to assure fail safe performance on a second failure, the specific load, its relationship to the EPDS and the repair time line shall dictate the specific approach.

6.2.3.1.6 Grounding

All circuits shall be designed in accordance with the single point ground guidelines. All units shall be designed in accordance with a grounding specification such as MIL-B-5087B.

6.2.3.1.7 Uninterrupted Power

Power interruptions due to switching shall not exceed TBD milliseconds. In general the systems or loads that require uninterrupted power shall supply the necessary stored energy within their system to supply the power required during switching transients. Under some circumstances uninterrupted power can be obtained by the use of two AC to DC converters on redundant lines with diode isolation.

6.2.3.1.8 Depressurization

Experimental data indicates that the corona onset voltage at reduced pressure, is 230V RMS for 60 to 440 Hz and 320 VDC at 23°C. The voltage in any equipment that must operate during pressurization or repressurization of the Common Module shall have a maximum value of 200V RMS or 250 VDC.

These voltage limits shall be reduced for higher frequency and higher temperature.

6.2.3.1.9 Maintenance

All components of the EPDS shall be designed to be Orbital Replaceable Units.

All cables shall have connectors on both ends so that each end may be disconnected and the cable removed and replaced. All trays and passage ways through which the cable is fed shall be designed to permit easy passage of the connectors during cable removal and replacement.

Switches, circuit breakers and other EPDS components shall be designed to be readily replaced without requiring disconnection or connection of individual power lines. This can be accomplished by the use of connectors and plug-in units.

6.2.3.1.10 Power Distribution

Primary Power is supplied to the Common Module through the two (redundant) penetrators. An isolation transformer is mounted outside the module adjacent to each penetrator. The isolation transformer may also serve to reduce the voltage as necessary to prevent corona during depressurization. The primary distribution assembly which contains the primary bus circuit breakers are located adjacent to the transformers. These circuit breakers control and protect the power to the port interface and the secondary power distribution assembly. These circuit breakers are rated at 25 kW each. The secondary power distribution assemblies are located in the same rack as the primary distribution assemblies. The secondary power distribution assemblies contain the switches that control the receptacles. These switches are rated at 3 kW each and have overload protection for the circuit and receptacle. Four receptacle positions will be possible at each double rack position along the walls. While all the receptacle positions are not wired in all the modules, it will be possible to wire the receptacles to provide as much as 12 kW to any double rack position, or redundant power sources for critical loads.

The secondary distribution assembly also distributes power to the loads along the floor and ceiling and provides redundant power to critical housekeeping loads.

Figure 6.2.3.1.10-1 illustrates the functional block diagram for Common Module power distribution. Figure 6.2.3.1.10-2 illustrates the power distribution layout. The EPDS illustrated has an estimated weight of 489.02 kg.

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U. S. MODULE (SYNTHESIZED CONCEPT)

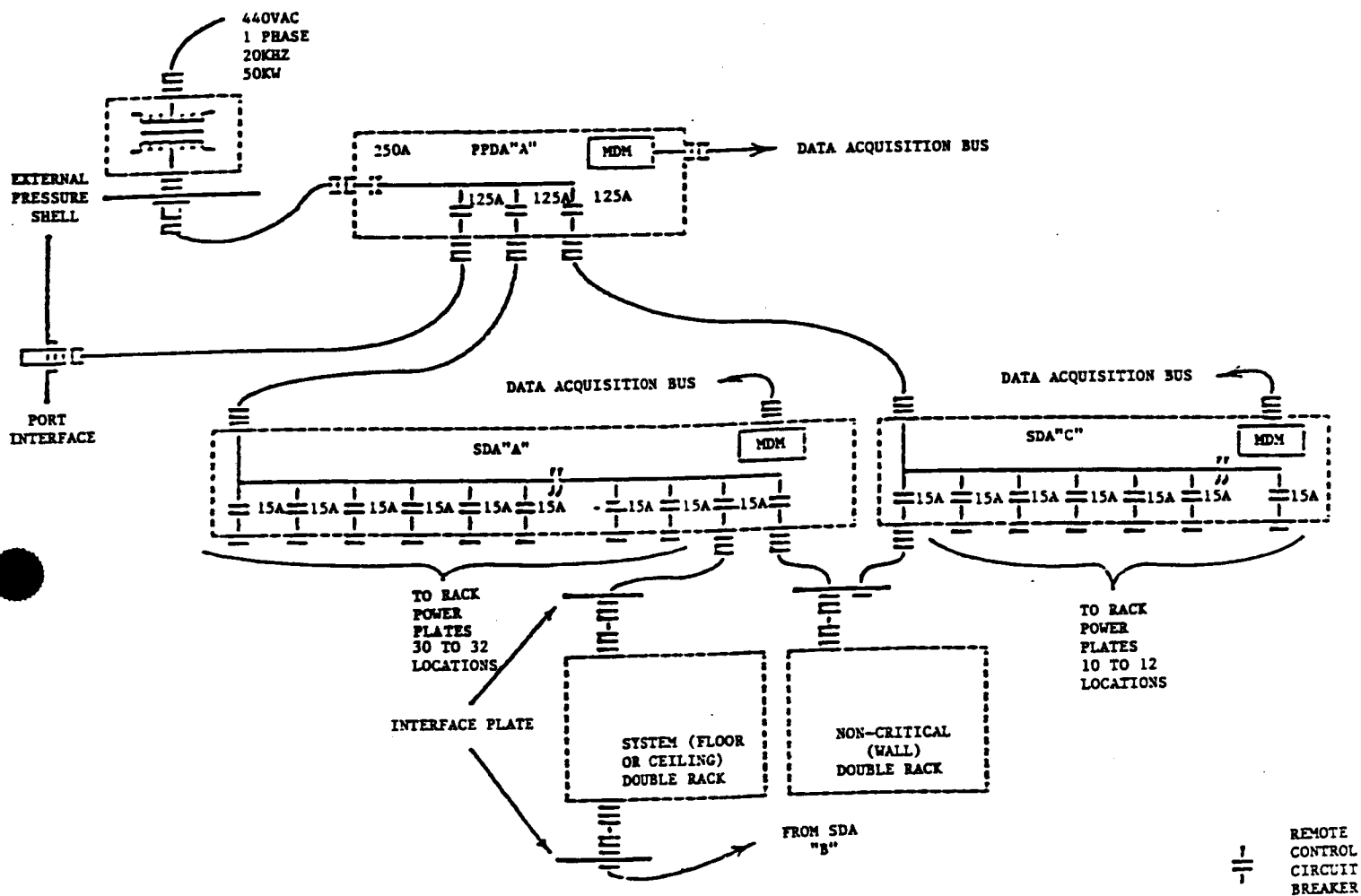


FIGURE 6.2.3.1.10-1 USL EPS FUNCTIONAL SCHEMATIC

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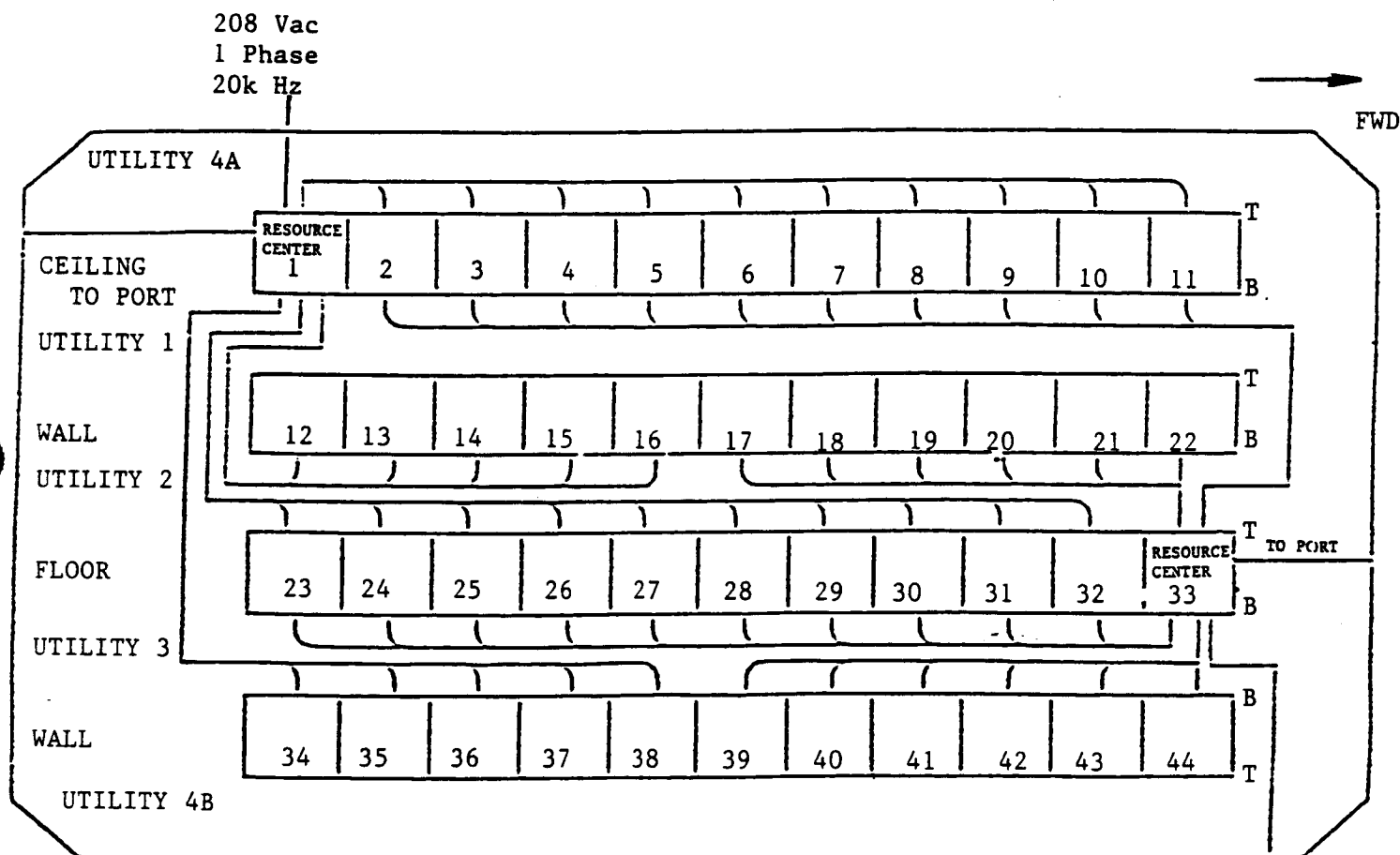


FIGURE 6.2.3.1.10-2 COMMON MODULE POWER DISTRIBUTION LAYOUT

6.2.4 Data Management Network Distribution System (DMNDS)

The Data Management Network Distribution System (DMNDS) consists of the elements of the Space Station Data Management System which are common to both the Habitat and Laboratory modules. WP-01 responsibilities include design of the DMNDS, installation and integration of DMNDS components, testing and check out of the DMNDS. The components which will make up the DMNDS are designed by the Data Management Architectural Center, WP-02.

The DMNDS, when integrated into the Common Module will provide the following services:

1)Crew Workstation Services, 2)Network Communication Services, 3)Instrumentation, 4)Data Transport Services, 5)Data Processing and Storage Services, Data Retrieval and Distribution Services 6)Common Module Subsystem Fault Detection /Isolation/Repair/ Services, and 7) Common Module Subsystem Test and Verification Services.

The DMNDS will be built from hardware components available from WP-02; these components include the following:

Global Core Network	- GCN
Star Coupler	- SC
Bridge	- BR
Module Network	- MDB
Standard Data Processor	- SDP
Embedded Data Processor	- EDB
Local Data Bus	- LDB
Multiplexer/DeMultiplexer	- MDM

Mass Memory Unit	- MMU
Fixed Multipurpose Applications Console	- FMPAC
Portable Multipurpose Applications Console	- PMPAC
Gateway	- GW
Network Interface Unit	- NIU
Bus Control Unit	- BCU
Bus Interface Adapter	- BIA

6.2.4.1 Baseline Configuration

The Common Module DMNDS will be a distributed processing environment that will allow for the fault tolerant management of the attached subsystems. The network will be configured in a hierarchical fashion using multiple layers of networks to attach the differing layers of processors. The layers of the DMNDS are described in the following sections (reference Figure 6.2.4.1-1 for a schematic of the DMNDS layout).

6.2.4.1.1 Global Core Network

The GCN will provide the communications media between the Common Module and other elements in the habitable section of the Space Station. The media will be capable of supporting data rates of at least 300 megabytes per second (Mbps) and will connect to the elements in the Common Module via a BR.

There will be one redundant GCN passing through each Common Module.

6.2.4.1.1.1 Star Coupler

The SC will be a common interface point for the GCN and any other fiber optic networks on the Space Station.

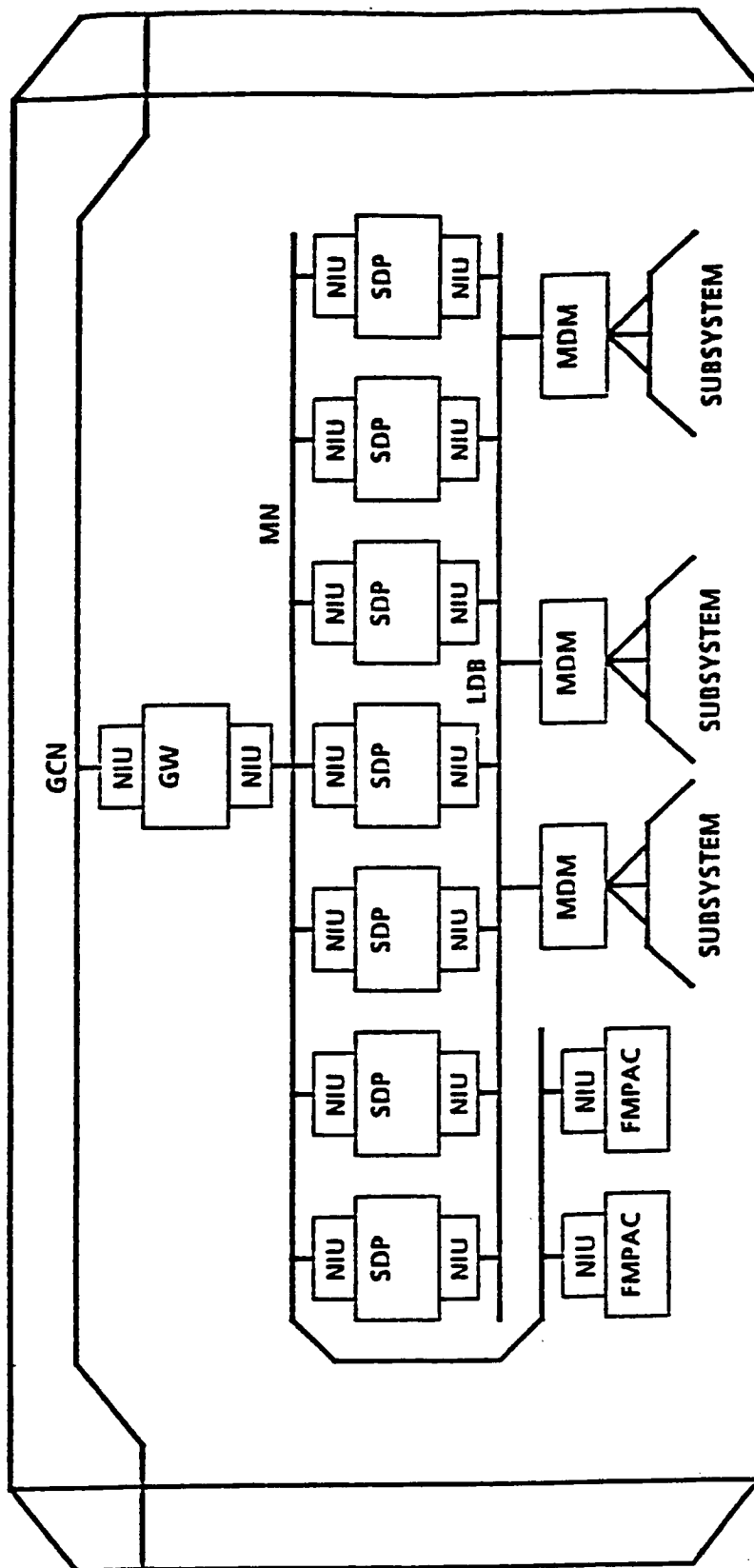


FIGURE 6.2.4.1-1 DMNDS LAYOUT

FIGURE 6.2.4.1-1 DMNDS LAYOUT

6.2.4.1.1.2 Fiber Optic Cable

The cabling used for the GCN will be fiber optic in order to handle the high data rates required while maintaining a low weight and volume.

6.2.4.1.1.2 Bridge

The bridge will provide for the transparent passage of data from the Common Module to the GCN and the other elements attached to it. Data transfer protocol will not be changed in the bridge. There will be one redundant set of BR's in the Common Module.

6.2.4.1.3 Module Network

The MN will provide a single common media for all processing elements in the Common Module such as the SDP and the EDP. The MN will transfer data using the same protocol as the SDP to assure commonality of services and transparency to the software. The MN will be capable of data rates of at least 100 Mbps. There will be one redundant set of MN's in the Common Module for housekeeping functions.

6.2.4.1.4 Processing Elements

The processing elements in the Common Module will provide for the distributed management of subsystems through a common programming environment. A family of processing elements will be available with varying processing capabilities within the family. All family members will run the same software, only at different speeds. By placing the processing elements in a distributed environment, tasks can be broken up to run on multiple processors concurrently to handle jobs too large or time consuming for even the largest of the processing family.

These processing elements will be capable of floating point mathematics, have a

minimum of 1 Mbyte of RAM (expandable to at least 16 Mbytes), a 32 bit data/instruction/address path, and a virtual memory architecture.

6.2.4.1.4.1 Standard Data Processor (SDP)

The SDP is a family of processing elements with a processing range of from approximately 1.0 to 4 MIPS (12 MIPS for growth to use of AI software) for complex instructions (i.e., not RISC). These processors all share a common architecture, instruction set, and operating system, and are constructed from a similar mix of ORU's common memory boards and communications devices) although processors of course be different. There will be redundant SDP's in the Common Module for housekeeping functions.

6.2.4.1.4.2 Embedded Data Processor (EDP)

The EDP is a low end family member of the SDP that will allow for its integration into a subsystem that needs closely coupled processing. The performance of the EDP will be at least 0.5 MIPS and it will have at least 0.5 Mbytes of RAM on board.

6.2.4.1.5 Local Data Bus

The LDB will provide the common communication media between the processing elements and the MDM's. The transfer protocol will be a subset of that used in the higher layers of the networking in the DMNDS that will be specifically tailored to handle real-time, burst data. The LDB will be capable of handling 10 Mbps data rates. There will be one redundant set of LDB.s for housekeeping functions within the Common Module.

6.2.4.1.6 Multiplexer/DeMultiplexer

The MDM will provide the interconnection to the subsystems that are monitored and controlled by the DMNDS. The MDM will be capable of handling a mix of analog and discrete/digital signals.

One MDM will be located in each rack within the Common Module to allow for management of resources within that rack (a minimum of 10 data and control points). The MDM's I/O will be expandable to accommodate a much larger number of data and control points for the management of any other subsystem or outfitted hardware within the same rack. One MDM will be able to access a mix of subsystems' data, allowing data acquisition to be managed by location rather than by subsystem. This feature will reduce the number of MDM.s required by providing for a truly distributed processing environment. Additional MDM's may be included within a rack if data acquisition rates are needed to be higher than what one MDM can provide.

Two important features of the installation of the MDM are the use of a single LDB for all housekeeping functions (i.e., a truly distributed environment, not subsystem specific) and no discrete cabling being run between racks of equipment except for the LDB. These features minimizes The number of connections at the interface plate to a single connector per bus (i.e., two in the case of a redundant system) which:

- a. Reduces weight and volume requirements
- b. Simplifies and standardizes the design of the interface plate
- c. Increases the hardware reliability by reducing the number of physical interconnects within the module.

Note that the requirements to place an MDM in each rack dictates that the MDM be a very low power device (there are 44 racks in each Common Module). The actual number of MDM's required and their configuration are yet to be determined.

6.2.4.1.7 Mass Memory Unit

The Mass Memory Unit will be a read/write random access device capable of storing at least 300 MBytes of volume shadowed data. This device will connect via a standard peripheral bus to two SDP's that will redundantly control the mass storage requirements of the Common Module. There will be one MMU per Common Module for housekeeping functions.

6.2.4.1.8 Fixed MPAC

The FMPAC will provide the user interface to the Common Module DMNDS processing systems. Services provided by the FMPAC will include the following: 1)Command entry, Voice synthesis/recognition, 2)Keyboard, 3)Six degrees of freedom analog controllers, 4)Status display, 5)Textual history, 6)Graphical history, 7)Hard copy of text and graphics, 8) Video display w/overlaid computer graphics 9)Crew caution and warning, 10)Dedicated switches/displays, 11)General purpose keyboard/display and 12) Audio Terminal Unit.

There will be one FMPAC per Common Module

6.2.4.1.8.1 Portable MPAC

The PMPAC will provide most of the services of the FMPAC, but will be mounted in a portable housing. Cabling to the PMPAC will be minimized to a simple data bus connection and, possibly, power (internal battery power would be pre-

ferred). Thermal dissipation will be designed to be radiative, obviating any requirement for conductive cooling. The following services will be provided by the PMPAC: 1)Command entry, 2)Keyboard Status display, 3)Textual history, 4) Graphical history, 5)Crew caution and warning, and 6)General purpose keyboard/display

There will be one PMPAC per Common Module; data bus interconnects for the PMPAC will be strategically located throughout the module.

6.2.4.1.9 Gateway

The Gateway is an outfitted element which will be a special interface between the MN and any outfitted or customer supplied data processing equipment that does not conform to the DMNDS data transfer protocol on the SDP and MDB. The Gateway will allow full duplex, bidirectional, transparent communications between the outfitted equipment and the Common Module systems.

6.2.4.1.10 Network Interconnect Devices

The devices described in the following section will allow for connection to the different data busses on the Space Station.

6.2.4.1.10.1 Network Interface Unit

The NIU will provide a common interface from the Common Module processing elements to the SDP, MN, and LDB. There will be one NIU for each SDP or EDP in the Common Module.

6.2.4.1.10.2 Bus Control Unit

The BCU will provide specialized serial and/or parallel data transfer protocols from a data bus to stand alone hardware elements in the Common Module. The BCU is an outfitted element.

6.2.5 Audio/Video Distribution Systems (AVDS)

6.2.5.1 AVDS Baseline

The AVDS consists of the equipments required to provide audio and closed circuit video communications within the Pressurized Module.

6.2.5.1.1 Description

The function of the AVDS is to generate, display, record, and transfer video data within the Pressurized Modules and to present and receive data through a C&T Interface with the ground and other Space Station interoperating elements. The AVDS also generates, records, controls, routes, and converts audio information within the Pressurized Modules. External audio communications will be through a C&T interface.

6.2.5.1.2 AVDS Elements

The following is a list of ORU candidates for the AVDS: 1)Audio Bus, Station, 2) Audio Bus, Log Module, 3)Transceiver, Crew, 4)Charger, Battery, Transceiver, 5) Audio I/F Unit, 6)Headset, 7)Recorder Assy, Audio, 8)Speaker Microphone Unit, 9)Wireless Audio Detector, 10)Wireless Interface Unit, 11)Video Cable Assy, Log Module, 12)Video Cable Assy, Hab Module, 13)Video Cable Assy, Lab Module, 14)Video Cable Assy, Intermodule, 15) Camera, Body, Internal, 16)Camera, Lens, Internal, 17)Pan/tilt, Unit Internal, 18) Camera, Body, Portable, 19)Camera, Lens, Portable, 20)Monitor, Viewfinder, 21)Attachment Assy., Video Camera, Portable, 22)Switch Assy., Video, 23) Sync. and Test Signal Generator, 24)Processor, Special Effects, and 25) Video Recorder.

6.2.5.1.3 AVDS Configuration

6.2.5.1.3.1 HSO AVDS

The communications systems in the HSO module consists of an internal audio and video system. These systems are described in the following sections.

6.2.5.1.3.1a HSO Audio System

The audio system in the HSO module, consists of several C&T rack mounted components which control the audio system, and distributed elements in the working areas of the module.

The C&T rack mounted components are the audio controller, wireless interface unit, and audio interface unit. The audio controller is the interface to the control and monitoring system which issues commands to the audio system, for such things as caution and warning messages, and receives status information about the audio system. The wireless interface unit is the wireless portion interface to the end-to-end audio system. It allows crew members to communicate via the wireless system to any part of the station or to the ground. The audio interface unit is the interface to the external C&T equipment which allows crew members in the Habitat Module to communicate to the ground or to other SS elements.

The distributed elements of the audio system in the Habitat Module are the speaker microphone, audio recorder, and the crew transceiver. The speaker microphone, located in the bulkheads, crew quarters, health maintenance facility, wardroom, galley, and MPAC, is the element by which crew members access the audio system. It consists of a speaker, microphone, keypad, (to select the various operational modes) and an operational jack for using a headset. From the speaker microphone a

crewmember can access any internal station location or the ground. The audio recorder is located in the Habitat HSO MPAC and is available via MPAC control to record two channels of audio communications upon demand. The crew Transceiver are used to access the wireless communications system. From the crew Transceiver a crew member can access any internal station location and the ground.

The elements of the audio system are interconnected by a station audio bus. These buses run through out the station allowing intermodule audio communications. The bus switching unit, located at either end of the Habitat Module allows the module to be isolated from the rest of the station in case of a failure.

6.2.5.1.3.1b HSO Video System

Operation of the video system in the HSO Module is similar to operation of a broadcast studio. At the heart of the system is a 32 x 16 baseband video switch. This switch operating under control of the Control and Monitor subsystem establishes proper interconnection of sources and sinks. Possible sources in the HSO include a video camera located at each end of the module on the endcone, two video recorders located in the MPAC, TBD sources from structure mounted cameras, TBD inputs from WP-02 RF links, and 8 sources from the interconnects (this includes intermodule baseband sources).

Possible sinks include 2 video monitors and two video recorders in the MPAC, TBD outputs to the WP-02 RF links, one monitor in the galley, and 8 sinks to the interconnects (this includes intermodule baseband sinks).

There will also be ten reconfigurable I/O ports evenly spaced throughout the mod-

ule. These will be used for portable cameras or monitors at various places throughout the module.

Cameras will have the capability of generating a test signal to test the signal characteristics of the path between the camera and any sink location. There will also be a test signal generator in the C&T rack used to test the signal path from the switch outputs to the sink devices and to the ground.

A sync. signal will be generated and sent to each camera to allow multiscree displays as well as limit crosstalk. Special effects for multiscreen display will be generated in the C&T rack and looped back to the video switch for distribution to the selected sink device. Graphics overlay of the video will occur in the MPAC.

6.2.5.1.3.2 USL AVDS

The communication systems in the USL consist of an audio and video system. These systems are described in the following paragraphs.

6.2.5.1.3.2a USL Audio System

The audio system in the USL module consists of several C&T rack mounted components which control the audio system, and distributed elements in the working areas of the module.

The C&T rack mounted components are the audio controller, wireless interface unit, and audio interface unit. The audio controller is the interface to the control and monitoring system which issues commands to the audio system, for such things as caution and warning messages, and receives status information about the audio system. The wireless interface unit is the wireless audio portion interface to the end-to-end audio system. It allows crew members to communicate via the wireless

system to any part of the station or to the ground. The audio interface unit is the interface to the external C&T equipment which allows crew members in the USL Module to communicate to the ground or to other SS elements.

The distributed elements of the audio system in the USL Module are the speaker microphone, audio recorder, and crew transceivers. The speaker microphone, located in the bulkheads, electronic workstation, and MPAC, is the element by which crew members access the audio system. It consists of a speaker, microphone, keypad (to select the various operational modes) and an optional jack for using a headset. From the speaker microphone a crew member can access any internal station location or the ground. The audio recorder is located in the USL MPAC and is available via MPAC control to record two channels of audio communications upon demand. The crew transceivers are used to access the wireless communication system. From the crew transceiver crew member can access any internal station location and the ground.

The elements of the audio system are interconnected by a station audio bus. These buses run through out the station allowing intermodule audio communications. The bus switching unit, located at either end of the USL module allows the module to be isolated from the rest of the station case of a failure.

6.2.5.1.3.2b USL Video System

Operation of the video system in the USL is similar to operation of a broadcast studio. At the heart of the system is a 32 x 16 baseband video switch. This switch operating under control of the Control and Monitor subsystem establishes proper interconnection of sources and sinks. Possible sources in the USL include a video

camera located at each end of the module on the endcone, two video recorders located in each MPAC, TBD sources from structure mounted cameras, TBD inputs from WP-02 RF links, and 8 sources from the interconnects (this includes inter-module baseband sources).

Possible sinks include 2 video monitors and two video recorders in each MPAC, TBD outputs to the WP-02 RF links, one monitor in the Electronics Workbench, and 8 sinks to the interconnect (this includes intermodule baseband sinks).

There will also be ten reconfigurable I/O ports evenly spaced throughout the module. These will be used for portable cameras or monitors at various places throughout the module, as well as experiment support (the current design does not accommodate high resolution video).

Cameras will have the capability of generating a test signal to test the signal characteristics of the path between the camera and any sink location. There will also be a test signal generator in the C&T rack used to test the signal path from the switch outputs to the send devices and to the ground.

A sync. signal will be generated and sent to each camera to allow multiscreen displays as well as limit crosstalk. Special effects for multiscreen display will be generated in the C&T rack and looped back to the video switch for distribution to the selected sink device. Graphics overlay of the video will occur in the MPAC.

6.2.6 Common Module Thermal Control System (TCS)

6.2.6.1 TCS Configuration

The TCS Configuration is a low-cost, minimum risk design that meets the requirements. This design was developed through trade studies and analyses that

considered technology readiness and emphasized minimum system complexity and maximum use of flight-proven hardware to evolve a minimum-cost design.

The Common Module TCS consists of three standard elements found in each module: a subsystem loop, an interconnect support loop and passive thermal control. The subsystem TCS consists of a single-phase, pumped-water loop that absorbs waste heat from the module interior and transfers it to the station central heat rejection system through external interface heat exchangers. A portion of the heat is rejected to both the 35° and 70°F central thermal utility buses. The subsystem loop provides coolant to life-critical module loads such as ECLSS, DMS, EPDS and avionics air cooling. The thermal transport capacity of the subsystem internal loop is 25 kW. The TCS includes a subsystem controller with manual override that automatically maintains coolant and flow and interfaces with the DMS. A single-phase water loop satisfies cabin safety and minimum development cost considerations. Two-fault tolerant (fail-operational/fail-safe) requirements are satisfied by redundant plumbing/pumping systems. TCS components are designed for on-orbit service, replacement, repair and minimum noise generation. Quick disconnects are provided at component interfaces to facilitate maintenance. The subsystem TCS is a closed coolant loop and, during normal operations, does not require expendable resupply.

The interconnect and resource node support loops are also a single-phase, pumped-water loop that services the logistics module and the airlock. The loop pump package and controls are located within these modules. Piping in the interconnects connect the pumping station to the logistics module and airlocks attached to the interconnect berthing ports. The

waste heat is transferred to the station control heat rejection and transport system via externally mounted interface heat exchangers. The transport capability of this loop is 25kw. All pressurized modules are wrapped with 30-layer MLI blankets to thermally decouple the module from external environment changes.

6.2.7 Crew Systems

The following paragraphs summarize Space Station - Related Crew Systems Requirements.

6.2.7.1 General Requirements: and Philosophies

Table 6.2.7.1-I is a list of Crew Station Design philosophies which the Crew Systems group is implementing. Philosophies regarding the design of human interfaces to Space Station software systems appear in Table 6.2.7.1-II.

6.2.7.2 Specific Requirements

The major sources of specific Crew Systems Requirements are listed below:

- a. Human engineering literature - sources such as original research reports, handbooks, standards and reference documents. Typical are:
- b. MIL-STD-1472
- c. MIL-STD-512
- d. JSC Ref. Doc 1024
- e. "Human Engineering Guide to Equipment Design," VanCott, Kinkade, U.S. Government Printing Office, 1972.
- f. Requirements contracts - Contracts whose purpose is to generate and

compile Space Station-specific detailed human engineering requirements are in progress. The major contracts of this type are:

- (1) Human Productivity (JSC)
- (2) Advanced EVA Systems (JSC)
- (3) Manned Systems Integration Standards (MSFC/JSC)

These requirements are communicated to the design organizations in the form of designer-oriented guidelines, memoranda and direct consultation with Crew Systems.

6.2.7.3 Derived Requirements

Most Crew Systems analyses are devoted to Deriving Requirements in the following areas some of which are: 1)Work Station Vision analysis, 2)Crew Activity definition, 3)Data Entry/display device trades, 4)Anthropometric non-modeling, 5)internal arrangements, 6)Anthropometric data base and 7)crew station anthropometric guidelines.

6.3 Environmental Control Life Support System (ECLSS)

6.3.1 Requirements

6.3.1.1 Functional Requirements

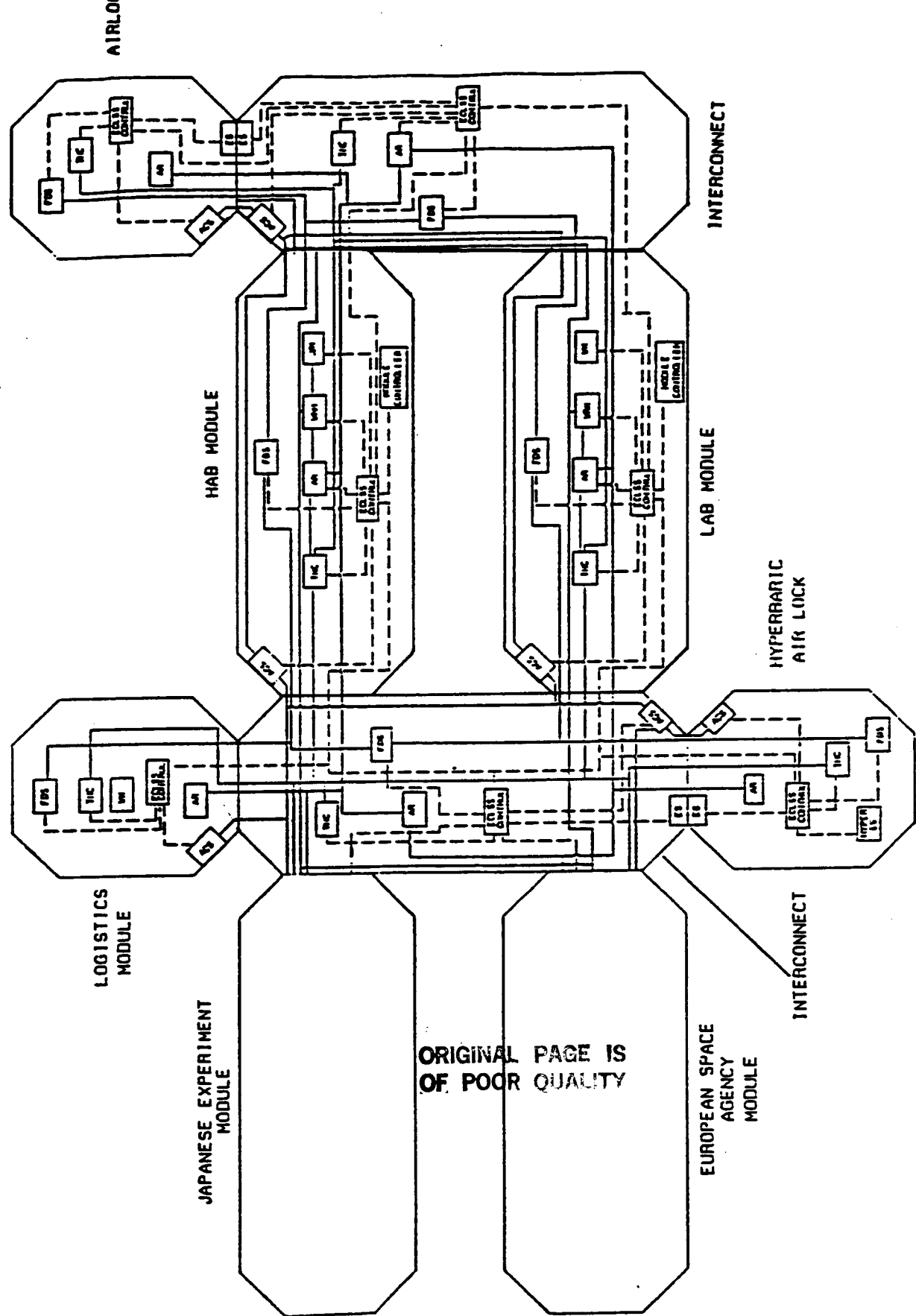
ECLSS functions include atmosphere control and supply, module temperature and humidity control, atmosphere revitalization, fire detection and suppression, water recovery and management, waste management and EVA support. Figure 6.3.1.1-1 illustrates a functional distribution concept of the ECLSS for the Space Station. Major subsystem elements will be located in the two U.S. Modules. The ECLSS shall accommodate the phased evolutionary

TABLE 6.2.7.1-I CREW STATION DESIGN PHILOSOPHIES

- Visual and aural clutter
 - Include only controls/displays required by task
 - Minimize clutter
- Control/display location
 - Co-locate related controls and displays
- Group functions
- Eye Reference Point (ERP)
 - Establish a single ERP
 - Design controls and displays to be operable from ERP
- Body restraints
 - Make body restraints adjustments such that all crew members can locate their eyes to ERP
 - Utilize foot restraints (preferred by astronauts)
- ERP indicator
 - Provide means for the crew member to determine when his/her body is located at ERP Use simple graphics or hardware
- Head/eye rotation
 - Locate controls/displays in reach/viewareas
 - Locate most critical control/displays in easiest reach/view areas
- Symbology readability/viewability
 - State requirements in terms of angles subtended by symbols
- Control standardization on following areas:
 - Shapes
 - Sizes
- Coding standardization in following areas:
 - Visual
 - Tactile
 - Shape

TABLE 6.2.7.1-II INFORMATION SYSTEM PHILOSOPHIES

- Ensure attention-getting characteristics of annunciations
- Categorize annunciations according to urgency of response
- Avoid overloading crew member with information he doesn't need
- Provide crew member with easy access to information he does need
- Minimize memory items
- Use read/do procedures for less time critical annunciations
- Use memory procedures where fast response is critical
- Use aural for getting attention
- Use visual annunciation for providing details regarding the annunciation
- Combine aural, text, control lighting, and dedicated lights in a logical system using each medium for what it does best regarding human interface.
- Integrate annunciations with simplified procedures
- Provide controlled annunciation cancellation capability
- Minimize number of annunciations
- Keep system quiet, dark



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FIGURE 6.3.1.1-1 SPACE STATION ECLSS SYSTEM/SUBSYSTEM FUNCTIONAL INTEGRATION CONTROL

growth of the Space Station. The ECLSS shall embody regenerative concepts to minimize the use of expendables. The following is a brief description of the ECLSS functions:

- a. Atmosphere control and supply. Atmospheric pressure and composition control functions shall provide a method of monitoring and regulating the partial and total pressure of gases in the module atmosphere. Makeup gas for pressurized volume leakage and airlock losses shall be provided.
- b. Module temperature and humidity control. The temperature and humidity shall be controlled in each pressurized module. These control systems shall provide ventilation throughout all areas of the pressurized modules.
- c. Atmosphere revitalization. Atmospheric revitalization systems shall regenerate the module atmosphere, as necessary, to provide a safe and habitable environment for the crew. Monitoring and control of odor and contaminants defined in paragraph 2.2.10.2.2 of Section 3, Rev. A of JSC 30000 shall be provided.
- d. Fire detection and suppression. A means of fire detection and suppression shall be included in each module, for fires internal to the Space Station.
- e. Water management. The collection, processing, and dispensing of water to meet evolving Space Station crew and experimental needs shall be ac-

commodated. Pretreating of waste water to prevent chemical breakdown and microbial growth prior to processing shall be provided. Post treatment systems and a monitoring system to ensure proper water quality shall also be provided to control and monitor contaminants prior to water use.

- f. Waste management. A means of collection and processing of Space Station waste products (e.g., metabolic waste, food/packing, regenerative process effluents, hard copy waste, etc.) for conversion to useful products or return to Earth shall be provided.

6.3.1.2 Design and Performance Requirements

The design and performance requirements for the ECLSS are outlined below.

- a. Atmosphere control and supply
 - (1) The Space Station shall provide an internal environment adequate to support and maintain crew comfort, convenience, health and well-being through all operational phases.
 - (2) The ECLSS shall have the capability to accommodate atmospheric leakage of each module up to 0.23 kg/day (0.5 lb/day) with a maximum of 2.3 kg/day (5 lb/day) for the total Space Station pressurized volume.
 - (3) The capability shall exist for dumping the atmosphere of a pressurized module overboard in the event of contamination or fire within that vol-

ume. For sizing the ECLSS, a single repressurization from zero to 1×10^5 N/M² (14.7 psia) shall be accommodated for a single module within a logistics resupply cycle.

b. Temperature and humidity control.

- (1) The respirable atmospheric composition, temperature/humidity variation, and ventilation levels provided by the ECLSS shall meet the requirements in Tables 6.3.1.2-I and 6.3.1.2-II.
- (2) Crew members shall be able to select the module temperature within specified ranges inside the individual modules.
- (3) The ECLSS shall interface with the Thermal Control Subsystem (TCS) for removal of waste heat from the pressurized modules.
- (4) The ECLSS shall provide the capability to cool avionics equipment via air cooling flow.

c. Atmosphere revitalization.

- (1) Oxygen shall be supplied by a process that does not require continuous resupply from the ground.

Handwash/hygiene wash	1.8 kg/man/day	(4 lb/man/day)
Shower	3.6 kg/man/day	(8 lb/man/day)
Laundry	12.5 kg/man/day	(27.5 lb/man/day)
Dishwasher	5.4 kg/man/day	(12 lb/man/day)

- (4) The ECLSS shall provide potable and hygiene water at controlled temperature for distribution throughout the Space Station pressurized areas.

- (2) A supply of nitrogen shall be available to provide makeup gasses and an initial supply for pressurization as required.

- (3) The Space Station shall use a regenerative process for CO₂ removal and subsequent processing.

- (4) Planned overboard venting of gasses shall be limited to those gasses that will not degrade the performance of either subsystem components exposed to Space or user facilities and experiments. Gas venting that is permitted shall be minimized, controlled and nonpropulsive.

d. Fire detection and suppression.

e. Water management.

- (1) Potable, hygiene, and waste water shall be provided.
- (2) Drinking water shall be provided by a closed-loop recovery process.
- (3) A recovery process for hygiene water shall be provided with the following capacity:

- f. Waste management. Waste management shall be provided to meet man-systems requirements and interfaces. Methods to efficiently process the

**TABLE 6.3.1.2-I RESPIRABLE ATMOSPHERE/WATER REQUIREMENTS
(CUSTOMARY UNITS)**

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED (1)	28-DAY EMERGENCY
CO ₂ Partial Pressure	mmHg	3.0 max	7.6 max	12 max
Temperature	deg F	65-75	60-85	60-90
Dew Point (2)	deg F	40-60	35-70	35-70
Potable Water	lb/man-day	6.8-8.1	6.8 (3)	6.8 (3)
Hygiene Water	lb/man-day	12 (3)	6 (3)	3 (3)
Wash Water	lb/man-day	28 (3)	14 (3)	0
Ventilation	ft/min	15-40	10-100	5-200
O ₂ Partial Pressure (4)	psia	2.83-3.35	2.4-3.45	2.3-3.45
Total Pressure (5)	psia	14.5-14.9	14.5-14.9	14.5-14.9
Dilute Gas	—	N ₂	N ₂	N ₂
Trace Contaminants (8)	mg/m ³	TBD	TBD	TBD
Micro-organisms	CFU/m ³ (6)	500 (7)	750 (7)	1000 (7)

NOTES:

- (1) Degraded levels meet "fail operational" criteria
- (2) Relative humidity shall be within the range of 25-75 percent
- (3) Minimum
- (4) In no case shall the O₂ partial pressure be below 15.0 N/M² (2.3 psia) or the O₂ concentration exceed 23.8 percent of the total pressure at 14.7 psia or 30 percent of the total pressure at 10.2
- (5) All systems shall be compatible with both 10.2 and 14.7 psia total pressure
- (6) CFU - Colony Forming Units
- (7) These values reflect a limited base. No widely sanctioned standards are available
- (8) Based on NHB 8060.1B (J8400003)

TABLE 6.3.1.2-II RESPIRABLE ATMOSPHERE WATER REQUIREMENTS (SI UNITS)

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED (1)	28-DAY EMERGENCY
CO ₂ Partial Pressure	N/m ²	400 max	1013 max	1600 max
Temperature	°K	291.5-297.1	288.8-302.6	288.8-305.4
Dew Point (2)	°K	277.6-288.8	273.9-294.3	273.9-294.3
Potable Water	kg/man-day	3.1-3.7	3.1 (3)	3.1 (3)
Hygiene Water	kg/man-day	5.44 (3)	2.72 (3)	1.36 (3)
Wash Water	kg/man-day	12.7 (3)	6.35 (3)	0
Ventilation	m/sec	.076-.203	.051-.508	.025-1.016
O ₂ Partial Pressure (4)	N/m ² x 10 ³	19.5-23.1	16.5-23.7	15.8-23.7
Total Pressure (5)	N/m ² x 10 ³	99.9-102.7	99.9-102.7	99.9-102.7
Dilute Gas	—	N ₂	N ₂	N ₂
Trace Contaminants (8)	mg/m ³	TBD	TBD	TBD
Micro-organisms	CFU/m ³ (6)	500 (7)	750 (7)	1000 (7)

NOTES:

- (1) Degraded levels meet "fail operational" criteria
- (2) Relative humidity shall be within the range of 25-75 percent
- (3) Minimum
- (4) In no case shall the O₂ partial pressure be below 15.0 N/M² (2.3 psia) or the O₂ concentration exceed 23.8 percent of the total pressure at 14.7 psia or 30 percent of the total pressure at 10.2
- (5) All systems shall be compatible with both 10.2 and 14.7 psia total pressure
- (6) CFU - Colony Forming Units
- (7) These values reflect a limited base. No widely sanctioned standards are available
- (8) Based on NH8 8060.18 (J8400003)

solid wastes into inert products for easy disposal or processing also shall be provided. A minimum of two independent waste collection systems (for both fecal and urine collection) shall be provided. These provisions shall be private and designed to be easily and conveniently cleaned and maintained. The systems shall not contaminate the cabin atmosphere with waste material, bacteria, toxicants, or noxious odors.

- g. Safe haven. The ECLSS shall accommodate the safe haven requirements in Paragraph 2.1.11.2.2 of JSC 30000 Section 3, REV A.

6.3.2 ECLSS Baseline Design

The Environmental Control and Life Support System (ECLSS) provides life critical support for the crew and cooling for electrical equipment. The ECLSS is important to crew comfort, safety and productivity. It significantly affects power consumption and logistics.

6.3.2.1 Baseline Configuration

The baseline ECLSS primarily provides four, four-man ECLSS systems, 2 per U.S. module, to support a crew of eight with dual redundancy and safe haven capability. Most of the ECLSS functions are provided in all U.S. elements in varying degrees of completeness/complexity. Reference Figure 6.3.1.1-1 for the ECLSS functional distribution. Any man tended option would require less ECLSS than the baseline configuration.

6.3.2.2 ECLSS Technical Description

The ECLSS is composed of the subsystems listed below. A working description

of each subsystem is presented in this section.

- a. Temperature and Humidity Control (THC) – Air Temperature Control, Humidity Control, Ventilation, Equipment Air Cooling, Common Module Services
- b. Atmosphere Control and Supply (ACS) – O₂/N₂ Pressure Control Vent and Relief O₂/N₂ Storage and Distribution.
- c. Atmosphere Revitalization (AR) – CO₂ Removal, CO₂ Reduction, O₂ Generation, Contamination Control and Monitoring
- d. Fire Detection and Suppression (FDS)
- e. Water Recovery and Management (WRM) – Urine Processing Hygiene, Water Processing, Potable Water Processing, Water Storage and Distribution, Water Thermal Conditioning, Common Module Water Services
- f. Waste Management (WM) – Urine Collection Return Waste Storage, Fecal Collection and Processing, Trash Collection and Processing, General Housekeeping

6.3.2.3 Temperature and Humidity Control (THC)

The Space Station (SS) THC provides module temperature and humidity control, intermodule ventilation, avionics cooling and module services (refrigerator/freezer, and freezer). The respirable atmospheric requirements include operational ranges for module temperature, dew point, venti-

lation flow and contamination levels. The operational parameters along with the air thermal loads determine the design requirements for the THC subsystem.

The Space Station THC subsystem consists of separate assemblies for each function for simplifying thermal control and minimizing off-gassing concerns. All major THC components are of conventional design and the overall system is similar to that flown on the Orbiter.

6.3.2.3.1 Module Temperature and Humidity Control

The module THC assembly includes sub-assemblies for module THC, module ventilation and air distribution ducts. The module air temperature is regulated by varying the air supply temperature in response to the Module Air Temperature selector settings. Warm moist module air is drawn in the THC by a fan. A portion of the entering air is passed through a condensing heat exchanger where it is cooled and partially dried. The water condensed from the air is removed by water separators and delivered to the Water Recovery and Management (WRM) subsystem. The cooled air is mixed with the remaining portion of the entering air, that has bypassed the heat exchanger, and returned to the module. The module air dew point and temperature control are interdependent. The temperature controller adjusts the air flow through the heat exchanger and the air bypass loop to maintain the module temperature at the desired set point and provide humidity condensate to the water separator. Temperature and dew point sensors monitor the input and output air flow to provide inputs to the temperature controller for its control functions. The THC fan package has two axial fans. One fan operates continuously and the other provides redundancy. The fan circulates module air through the heat exchanger

and back into the cabin. A discharge check valve is provided with each fan to prevent back flow. Silencers in the air intake and discharge ducts reduces fan noise. The air flow in the ducts is 20 ft/sec which minimizes air flow noise.

The air/water mixture from the condensing heat exchanger is removed by a slurrer and sent to a centrifugal water separator package. This package has two units. One water separator operates continuously and the other provides redundancy.

The THC is designed to remove a maximum of 6500 watts of heat from the module air. This includes both module sensible and latent heat loads. The THC design dewpoint is 50°F with a latent heat load peak of 1.6 Kg (3.5 lbs)/hour.

The water removal capacity of the THC is a function of the sensible heat removal.

The cooled dry air from the THC heat exchanger is supplied through ducts for ventilation of the module and breathing by the crew. The Air Revitalization System (ARS) removes 30 SCFM for CO₂ removal and exhausts the output of the CO₂ removal system into the THC return duct. The contamination controller receives 4 CFM of this air for removal of airborne contaminants.

The ventilation flow path is from the ceiling to the floor. This provides a convective flow around the crew and assures that loose items "fall" to the floor. Ten ceiling mounted air diffusers with 7.6 induction ratios provide thermal velocities of 150 ft/min at 59" to give 20 ft/min average in the module. Two ventilation makeup fans in the ceiling supplement the THC airflow to cool the crew and maintain uniform distribution of the air.

High Efficiency Particulate Air (HEPA) filters are located in the 8 THC return vents to maintain class 100,000 clean air environment. The combined filter volume of 5.8 ft³ was determined by the steady state bacteria or colony forming unit control requirements for a crew of 4/module, particulate loading on pressure drop and change out period.

6.3.2.3.2 Intermodule Ventilation

Intermodule ventilation is provided to all pressurized SS elements to supply the crew with fresh processed air for breathing regardless of their location with respect to the module ARS and to transport the CO₂ produced by the crew to the operating ARS. The airflow operates with any or all hatch doors opened or closed, modules isolated, or dead ended modules in place or removed.

The process air flow required for resource node to maintain the CO₂ partial pressure to less than 3 mm Hg is 10-20 CFM per crew member. The CO₂ air flow requirements is greater than that for Humidity and O₂ concentration control. the process air flow rate is 140 CFM. This requires a duct size of 4.7 inch diameter at 20 CFM.

Isolation valves are located on both sides of all hatches to direct air flow and isolate SS elements when necessary. Process air from adjacent resource node is fed into the module THC ventilation return duct upstream of the THC fan package. This fan pulls the air from the resource node and feeds it through the module condensing heat exchanger and ARS into the THC ventilation supply duct which supplies the process air to the next resource node. The head rise for the process air flow is provided by the THC fan in each module.

6.3.2.3.3 Avionics Cooling

The Avionics cooling assembly includes subassemblies for avionics cooling and avionics air distribution. The Avionics Cooling Assembly removes heat from the module equipment racks by supplying cool air to and removing heated air from each rack. This assembly also supplies Fire Detection Suppression (FDS) air flow to each powered equipment rack and to each storage rack containing combustible material. The heated air and FDS air is drawn into the Avionics Cooling Assembly by a fan which sends it through a sensible heat exchanger and cooled.

The Avionics Cooling subassembly is designed to remove 10.0 Kw of sensible heat from the module equipment racks. The airflow provided by the fans through the heat exchanger to the air distribution system is constant. The airflow to each rack is adjustable to provide the air cooling required by the equipment in the rack. The minimum air cooling supplied to any single equipment rack (SER) is 1.5 Kw and 3.0 Kw to any double equipment rack (DER). The minimum airflow to any SER is 13.5 CFM and 27 CFM to any DER for FDS.

The air flow distribution divides the module into 8 zones of 11 SER (5 1/2 DER) each. These zones are composed of racks forward and aft of the module crossover racks located in the center of each wall. The maximum cooling to any one zone is 5.0 Kw. The 8 zones are further divided into 2 sides of 4 zones each. The four zones in each side are in parallel and the 2 sides are in parallel. the maximum power available to any one side is 7.0 Kw.

The air flow to an individual rack is adjusted automatically by air flow valves in

each rack. The Data Management System (DMS) senses the power being supplied to the rack and sends this data to the ECLSS Standard Data Processor (SDP). The SDP calculates the required air flow rate, control valves area and valve position. The SDP then sends a signal through the DMS to the valve actuator to drive to the calculated position. Using the rack power information rather than the rack exit temperature prevents control loop oscillations.

The equipment and storage racks to be air cooled are enclosed to maintain the concept for separate module THC and avionics cooling environments. There will be some air interchange between the two environments over the life of the station. Contamination from off-gassing and smoke will be controlled by the contamination controller and HEPA filters.

6.3.2.3.4 Refrigerator/freezer, freezer

The galley is required to provide refrigerated and frozen food storage to supply food for 8 crew members for 14 days. The logistics module requires 31 ft³ of refrigerated food and 63 ft³ of frozen food for each resupply interval of 90 days for a crew of eight. These requirements coupled with varying resupply intervals, crew sizes and Space Station growth scenarios determines the optimum packaging of a refrigerator/freezer to be in a single equipment rack (SER) with a freezer volume of 10 ft³ and refrigerator volume of 15.6 ft³. The freezer is also in a SER with an internal volume of 25.6 ft³. The IOC prime configuration has one refrigerator/freezer in the HAB and two in the Logistics module.

The vapor compression technology is the selected concept for the refrigerator/freezer and freezer. The design is based upon proven technology and is the most efficient system to operate. The design in-

corporates double containment of the freon loop to prevent leakage into the atmosphere. Liquid to liquid heat exchangers will remove heat from the units. Each unit (rack) is supplied with avionics cooling air, fire detection and suppression capability, data management system and power interfaces and instrumentation for control and monitoring.

6.3.2.4 Instrumentation Requirements

A sensor list for ECLSS has been prepared using the IOC Prime configuration based on preliminary requirements for control and monitoring. Table 6.3.2.4-I, lists the major ECLS subsystems and their distribution in each module. The data for the summary was obtained from mechanical schematics and equipment lists supplied by manufacturers of ECLSS subsystems.

Data contained in these Tables will change as the ECLSS configuration and equipment selection change. This preliminary information points to the magnitude and complexity of the control, monitoring and fault isolation requirements of the ECLSS. The sensors and subsystems for control/monitoring the ECLSS shall be selected

from commonality items where possible to minimize the qualification of components and reduce inventory. Other sensors and subsystems will be selected based upon the measuring application, performance requirements, reliability, maintainability, safety and cost.

Sensors in mission critical subsystem shall be designed such that no single failure shall cause the loss of a redundant path. The control/monitor instrumentation systems will be designed for automatic process and control and shall provide monitoring and control functions; subsystems mode transition; fault diagnostics

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8

NOMENCLATURE	DISTRIBUTION							TOTAL UNITS	VOL CUFT	AVG POWER WATT
	HAZ 1	MTL	LOG 1	LOG 2	FIC	AIC	AL			
WASTE MANAGEMENT SUBSYSTEM										
HUMAN WASTE COLLECTION ASSY										
COMMODE SUBASSY	1	1	0	0	0	0	0	188	28.3	80.04
CHUCK DISCONNECT	4	4	0	0	0	0	0	0.5	0.1	0
SOLID WASTE COLLECT & PROC ASSY										
TRASH COLLECTION SUBASSY	1	1	0	0	0	0	0	55	14.2	50
VACUUM CLEANER SUBASSY	1	1	0	0	0	0	0	25	1	50
TRASH COMPACTOR SUBASSY	1	0	0	0	0	0	0	110	14.2	4.0
WATER RECOVERY & MGT SUBSYSTEM										
URINE PROCESSING ASSY										
URINE PRE-TREATMENT SUBASSY	2	2	0	0	0	0	0	26.7	2.15	13.5
URINE STORAGE TANK SUBASSY	2	2	0	0	0	0	0	26.7	2.15	0
AIR EVAPORATOR SUBASSY	2	2	0	0	0	0	0	168	9.27	148.5
WATER QUALITY MONITOR SUBASSY	2	2	0	0	0	0	0	43	3.58	40.5
VALVES	14	14	0	0	0	0	0	1.4	.01	0.175
CHUCK DISCONNECT	14	14	0	0	0	0	0	0.5	0.1	0
PLUMBING	1	1	0	0	0	0	0	10	0.5	0
POTABLE WATER COLLECT, PROC, & DIST										
CONDENSATE STORAGE TANK SUBASSY	1	1	0	0	0	0	0	40	5.7	0
MULTI-FUNCTION SUBASSY	1	1	0	0	0	0	0	226	4.9	76.5
MICROBIAL CHUCK VALVE SUBASSY	1	1	0	0	0	0	0	1.5	0.2	0
WATER QUALITY MONITOR SUBASSY	1	1	0	0	0	0	0	40	3.58	40.5
POTABLE WATER STORAGE TANK SUBASSY	2	2	0	0	0	0	0	40	5.7	0

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

NOMENCLATURE	DISTRIBUTION							TOTAL UNIF WT	VOL CUFT	AVG POWER WATT
	IIAB 1	MTL	LOG 1	LOG 2	FIC	AIC	AL			
POTABLE WATER COLLECT, PROC & DIST										
POTABLE WATER DISPENSING SUBASSY	2	1	0	0	0	0	0	15	0.5	9.96
VALVE	75	75	0	0	22	20	0	1.4	0.01	0.175
QUICK DISCONNECT	75	75	0	0	22	20	0	0.5	0.1	0
PLUMBING	1	1	0	0	1	1	0	52	0.2	0
WATER RECOVERY & MGT SUBSYSTEM										
HYGIENE WATER COLLECTION, PROCESSING & DISTRIBUTING ASSY										
WASTE HYGIENE WATER STORAGE TANK SUBASSY	1	1	0	0	0	0	0	120	16	0
MULTIFILTRATION SUBASSY	1	1	0	0	0	0	0	370	26.49	76.5
MICROBIAL CHECK VALVE SUBASSY	1	1	0	0	0	0	0	1.5	0.2	0
WATER QUALITY MONITOR SUBASSY	1	1	0	0	0	0	0	40	3.58	40.5
HYGIENE WATER STORAGE TANK SUBASSY	1	1	0	0	0	0	0	120	16	0
VALVE	110	110	0	0	20	20	0	1.4	.01	.175
QUICK DISCONNECT	110	110	0	0	20	20	0	0.5	0.1	0
PLUMBING	1	1	0	0	1	1	0	80	2	0
WATER REPLENISHMENT ASSY										
WATER REPLENISHMENT TANK SUBASSY	0	0			12	0	0	40	5.4	0
VALVE	0	0			25	0	0	1.4	.01	.175
QUICK DISCONNECT	0	0			25	0	0	0.5	0.1	0
PLUMBING	0	0			1	0	0	8	0.5	0

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TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

NOMENCLATURE	DISTRIBUTION							TOTAL UNIT WT	VOL CUFT	AVG POWER WATT
	HAB 1	MTL	LOG 1	LOG 2	FIC	AIC	AL			
FIRE DETECTION SUBSYSTEM										
FIRE DETECTION ASSY										
FIRE DETECTION SUBASSY	1	1	0.2	0.2	0.1	0	0.2	31.4	0.34	89
PYRO CONTROL BOX SUBASSY	1	1	0.5	0.5	0	0	0.5	6.8	0.25	5.2
FIRE SUPPRESSION ASSY										
FIRE EXTINGUISHER SUBASSY	1	1	0.5	0.5	0	0	0	69.0	1.1	0
PORT FIRE EXTINGUISHER SUBASSY	2	2	2	2	1	0	0	6.9	.11	0
EMERGENCY BREATHING PACK SUBASSY	8	8	2	2	3	0	0	17.6	0.5	0
PLUMBING	1	1	0.5	0.5	0	0	0.5	32.0	.03	0
VALVES	30	30	15	15	0	0	15	1.0	.01	0.2
FDS CONTROLLER ASSY	1	1	0.5	0.5	0	0	0.5	10	0.41	15
ATMOSPHERE CONTROL & SUPPLY SUBSYSTEM										
ATMOSPHERIC COMPOSITION MONITOR	1	1	0	0	0	0	0	20	1.0	20
O2/N2 STORAGE ASSY										
LIQUID OXYGEN STORAGE	0	0	1	1	0	0	0	259	22	10
LIQUID NITROGEN STORAGE	0	0	3	3	0	0	0	443	83	49
HIGH PRESSURE DISTRIBUTION VALVES (EXTERNAL)	40 0	40 0	0 0	0 0	22 6	10 6	0 6		1.34	0
LOW PRESSURE DISTRIBUTION VALVES (INTERNAL)	40 8	40 8	20 4	20 4	50 24	10 24	0 4		1.42	.1

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

NOMENCLATURE	DISTRIBUTION							TOTAL UNIT WT	VOL CUFF	AVG POWER WATT
	HAAB 1	MTL	LOG 1	LOG 2	FIC	AIC	AL			
O ₂ /N ₂ STORAGE ASSY										
REPRESSURIZATION O ₂	1	0	0	0	0	0	0	136	9.8	0
REPRESSURIZATION N ₂	1	0	0	0	0	0	0	385	25.6	0
REPRESSURIZATION VALVES	0	10	0	0	0	0	0			
QUICK DISCONNECTS	4	4	4	4	24	4	0		1.13	0
O ₂ /N ₂ PRESSURE CONTROL ASSY	1	1	1	1	1	0	0	96.8	2.5	66.4
O ₂ PRESSURE CONTROL	1	1	1	1	1	0	0	48.4	1.25	33.2
N ₂ PRESSURE CONTROL	1	1	1	1	1	0	0	48.4	1.25	33.2
PRESSURE MONITOR & CONTROLLER	1	1	1	1	1	0	0	10	2.42	0
PRESSURE RELIEF & DEPRESS. ASSY	1	1	1	1	1	0	0	12.5	0.07	0.2
PRESSURE EQUALIZATION VALVE	2	2	1	1	6	0	0	1.4	.05	0
NEGATIVE PRESSURE RELIEF VALVE	1	1	1	1	1	0	0	3.5	.84	0
POSITIVE PRESSURE RELIEF VALVE	1	1	1	1	0	0	0	4.4	.84	0
EMERGENCY VENT VALVE	1	1	1	1	1	0	0	2.4	0.2	0
ACS CONTROLLER	1	1	0	0	0	0	0	10	1.0	0
TEMP & HUMIDITY CONTROL SUBSYSTEM										
CABIN TEMP & HUMIDITY CONTROL										
COND HEAT EXCHANGER SUBASSY	1	1	0	0	0	0	0	119	7.75	0
COND HEAT EXCHANGER SUBASSY (II)	1	1	0	0	0	0	0	119	227.75	0
CABIN AIR FAN SUBASSY	1	1	0	0	0	0	0	27.5	1.34	725
CABIN AIR FAN SUBASSY (II)	1	1	0	0	0	0	0	27.5	1.34	0
WATER SEPARATOR SUBASSY	1	1	0	0	0	0	0	16.2	1.42	11
WATER SEPARATOR SUBASSY (II)	1	1	0	0	0	0	0	16.2	1.42	0
TEMPERATURE CONTROL SUBASSY	1	1	0	0	0	0	0	6.3	1.13	0
TEMPERATURE CONTROL SUBASSY (II)	1	1	0	0	0	0	0	6.3	1.13	0

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIP-
MENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

NOMENCLATURE	DISTRIBUTION						TOTAL UNIFWT	VOL CUFT	AVG POWER WATT
	IIAB 1	MTL	LOG 1	LOG 2	FIG	AIC	AL		
CABIN TEMP & HUMIDITY CONTROL									
CABIN AIR DUCT ASSY	1	1	0	0	0	0	0	19.28	0
VENTILATION FAN SUBASSY	2	2	1	1	0	0	0	0.45	22
INTERMOD VENT ASSY									
PRESS. AIR DUCT SUBASSY	1	1	0.5	0.5	2.09	0.18	0.5	12.1	0
VALVES	4	4	2	2	12	0	2	4.0	0.2
THC CONTROLLER ASSY									
CABIN AIR CONTROLLER SUBASSY	1	1	0	0	0	0	0	10.0	15
AV COOLING CONTROLLER SUBASSY	1	1	1	1	0	0	0	10.0	15
AVIONICS COOLING ASSY									
AVIONICS IIR SUBASSY	1	1	0.5	0.5	0	0	0	46.5	0
AVIONICS IIR SUBASSY (II)	1	1	0.5	0.5	0	0	0	46.5	0
AVIONICS COOLING FAN SUBASSY	1	1	0.5	0.5	0	0	0	45.3	640
AVIONICS COOLING FAN SUBASSY (II)	1	1	0.5	0.5	0	0	0	45.3	0
AVIONICS COOLING DUCT SUBASSY	1	1	0.5	0.5	0	0	0	176.0	0
COMMON MODULE SERVICES ASSY									
REFRIGERATOR SUBASSY	1	0	2	2	0	0	0	190.0	35
FREEZER SUBASSY	0	0	2	2	0	0	0	190.0	35
ATMOSPHERE REVITAL SUBSYSTEM	2	2	0	0	0	0	0		
TRACE CONTAMINANT MONITOR	1	1	0	0	0	0	0	145	150
TRACE CONTAMINANT CONTROL ASSY	2	2	0	0	0	0	0	69	180
SPECIFIC SORBENT SUBASSY	1	1	0	0	0	0	0		
CHARCOAL FILTER SUBASSY	1	1	0	0	0	0	0		
CONTROLLER SUBASSY	1	1	0	0	0	0	0		

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Cont'd)

NOMENCLATURE	DISTRIBUTION						TOTAL UNIT WT	VOL CU FT	AVG POWER WATT
	IIAB 1	MTL	LOG 1	LOG 2	FHC	AIC			
COMMON MODULE SERVICES ASSY									
MICROBIAL ASSESSMENT	0	1	1	1	0	0	1	1.42	11
MICROBIAL CONTROL SUBASSY	1	1	0	0	0	0	10	1.0	200
CO ₂ REMOVAL ASSY	2	2	0	0	0	0	220	129	685
FAN SUBASSY	1	1	0	0	0	0			
SILICA GEL SUBASSY	1	1	0	0	0	0			
MOLE SIEVE SUBASSY	1	1	0	0	0	0			
HEAT EXCHANGER SUBASSY	1	1	0	0	0	0			
COMPRESSOR	1	1	0	0	0	0			
CO ₂ STORAGE SUBASSY	1	1	0	0	0	0			
INSTRUMENTATION	1	1	0	0	0	0			
VALVES	12	12	0	0	10	10			
CONTROLLER SUBASSY	1	1	0	0	0	0			
DISCONNECTS	40	40	0	0	0	0			
CO ₂ REDUCTION ASSY - BOSCH REACTOR	2	2	0	0	0	0	273	114	294
BOSCH REACTOR SUBASSY	1	1	0	0	0	0			
WATER SEPARATOR SUBASSY	1	1	0	0	0	0			
COMPRESSOR SUBASSY	1	1	0	0	0	0			
CONDENSOR/HEX SUBASSY	1	1	0	0	0	0			
FAN SUBASSY	1	1	0	0	0	0			
INSTRUMENTATION	1	1	0	0	0	0			
VALVES	12	12	0	0	0	0			
CONTROLLER SUBASSY	1	1	0	0	0	0			
DISCONNECTS	40	40	0	0	0	0			

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Concluded)

TABLE 6.3.2.4-I ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EQUIPMENT LIST CONFIGURATION IOC PRIME CREW SIZE 8 (Concluded)

NOMENCLATURE	DISTRIBUTION							TOTAL UNIT WT	VOL CUFT	AVG POWER WATT
	IIAB 1	MTL	LOG 1	LOG 2	FHC	AIC	AA			
COMMON MODULE SERVICES ASSY										
PLUMBING (FT) BETWEEN MODULES	43	43	0	0	50	50	0			
O ₂ GENERATION ASSY	2	2	0	0	0	0	0	102	2.1	840
PUMP SUBASSY	1	1	0	0	0	0	0			
THERMAL CONTROL IIX SUBASSY	1	1	0	0	0	0	0			
ELECTROLYSIS UNIT SUBASSY	1	1	0	0	0	0	0			
DEIONIZATION UNIT SUBASSY	1	1	0	0	0	0	0			
WATER ACCUMULATION TANK SUBASSY	1	1	0	0	0	0	0			
PRESSURE CONTROLLER SUBASSY	1	1	0	0	0	0	0			
INSTRUMENTATION	1	1	0	0	0	0	0			
CURRENT CONTROLLER SUBASSY	1	1	0	0	0	0	0			
VALVES	8	8	0	0	0	0	0			
CONTROLLER SUBASSY	1	1	0	0	0	0	0			
DISCONNECTS @ 33LBS EACH	60	60	0	0	0	0	0			
PLUMBING (FT)	10	10	0	0	0	0	0			

including fault prediction, fault detection, fault isolation, fault correction and fault correction instructions.

6.3.2.5 Sizing for Normal and Safe Haven Operation

The distributed components of the Common Module atmosphere management subsystem are designed for a normal four-person loading and can accommodate overloads resulting from crew concentration in a particular area or local high activity levels. Inequalities in load between modules are smoothed out by

forced intermodular ventilation. The temporary loss of a unit is not significant because the distributed configuration is inherently redundant and most units can exceed nominal performance for short periods.

The hygiene water management subsystem is sized for four persons in each Habitat Module but can accommodate eight crew members with more frequent filter change. Intermodule lines between module storage tanks permit usage of all stored water from a single module. The potable water management subsystem is sized for four persons in each module but can accommodate eight crew members. Intermodule lines permit usage of stored water from other modules. The waste management system in each Module is sized for four crew members but can accommodate all eight crew members with more frequent changeout to waste storage.

For safe haven or temporary contamination conditions, the ECLSS readily accommodates eight crew members within one habitable module if the two becomes uninhabitable. Furthermore, the stored oxygen and potable water supply of the one mod-

ule meet safe haven requirements if power for O₂ generation or water processing is limited.

6.3.2.6 Man-Tended Option

The man-tended ECLSS provides the following services:

- a. O₂/N₂ supply and control
- b. Ventilation
- c. Temperature and humidity control
- d. CO₂ removal and storage
- e. Trace contamination control
- f. Oxygen generation
- g. Trash collection
- h. Avionics cooling
- i. Fire detection and suppression
- j. MMU N₂ compressor

No food, water, waste management or safe haven capabilities are provided since all of these services are provided by the shuttle.

6.3.2.7 Major Analyses and Trades

All process and component trades and analyses are supported by additional data from subcontractors in ECLSS. Hamilton Standard, Garrett-Air Research, and Life Systems have Statements of Work encompassing evaluation of virtually the entire ECLSS. Other subcontractors will provide support in specific ECLSS areas.

The Boeing Parametric Cost Model (PCM) is used to compare life cycle costs for al-

ternative technologies compared in the trade studies.

6.3.2.8 Automation

6.3.2.8.1 Partitioning of Man/Machine Roles

ECLS subsystems have already evolved to configurations which are highly automated and which require a minimum of crew involvement.

The "machine" performed functions are more properly defined as "automatic" rather than "robotic" in that they consist primarily of the sequential/adaptive actuation of electrical devices such as valves, fans, pumps, heaters, etc. based on condition monitoring by status sensors and in response to controller/driver signals. Single (non repetitive) crew involvement at the initialization of subsystem operation (Or related/integrated group of subsystems) is considered to be within the definition of automatic.

Man involvement (Column B) exists under two separate headings: those in which man is an integral part of the function and which are unlikely to ever change significantly, e.g., hygiene functions; and those such as filter changes, tankage replacement, which are infrequent and which might be further automated (or robotized) based on weighing factors in further trades.

6.3.2.8.2 Technology Availability

The "automation", as described above, is fully supported by presently available equipment. Although there may be improvements over time in the efficiency/reliability of sensors and actuators and in the capacity/size of microprocessors, there are no manual tasks attributable to limitations in automation technology. Robotics technology has not been assessed at this

stage in system definition although manned tasks which have been acceptable in laboratory prototype equipment or short term flight programs (Shuttle) will be considered further based on such factors as:

- o contamination/safety risks
- o task/skill/cost factors, man vs. machine

6.3.2.8.3 Artificial Intelligence/Expert Systems

This terminology is viewed as an advancement in the degree of inter-package and overall system control integration. The ECLSS functions are not dependent on such advancement for fundamental operation. Advancement in the degree of centralized monitoring/control is viewed more as further reducing the already minimal crew load rather than in increasing system performance efficiency.

6.3.2.8.4 Technical Content and Performance Capabilities

The initial approach to subsystem control automation described above will require individual preprogrammed microprocessors at each subsystem or small groupings on integrated/interacting subsystems. This will allow each subsystem or group to be operated independently with a few simple start/stop/mode selection commands for checkout and test, as well as being independent of any overall system controller problems. This does not preclude integration into a total (vehicle) data management system for monitoring/coordination. The degree of such involvement and the details of the system architecture will be defined as system definition progresses.

6.3.2.9 Technology Assessment

An evaluation study was conducted to define the technology status of regenerative

ECLSS hardware. The evaluation considered candidate subsystems concepts which satisfy the major functions of ECLSS. The technology assessment reflects a review of information from,

- a. Current and planned NASA Advanced Development Programs, ECLSS Test Bed Program,
- b. Subcontractor development and IR&D projects and results of in-house ongoing IR&D programs.

The evaluation utilized the standard NASA defined levels of technology. The evaluation was conducted by reviewing the information available for each candidate processing subsystem with emphasis being placed on candidates for IOC station. Based on the data reviewed, each processing subsystem was assigned a level of technology maturity. Details can be found in Paragraph 6.5.2.9 of D483-50022-2 Rev C (DR02).

Past flight programs such as Apollo, Skylab and Orbiter have incorporated subsystem candidates applicable at Space Station.

NASA research and development contracting has resulted in the development of regenerative process concepts to the breadboard and prototype levels identified by maturity levels of 5 and 6.

In the era of regenerative process subsystems such as CO₂ removal, CO₂ reduction, oxygen generation and water recovery, there are competing candidates at equal or nearly equal levels resulting from NASA development contracts. The significance here being the flexibility available to the ECLSS designed during Phase C/D. The current technology status of ECLSS incorporates alternate options of nearly the same technology status in

the event the initial Phase C/D selection proves unsatisfactory.

In reviewing the overall technology status of ECLSS, processes were identified that were in earlier stages of development and as such were not applicable to the cost constraints placed on IOC station development. Assessment indications are that the overall technology status of the ECLSS is sufficiently advanced to meet IOC cost constraints.

6.3.2.10 Atmosphere Control and Supply (ACS)

The ACS must perform the following functions:

Oxygen Supply

Nitrogen Supply

Atmosphere Pressure Control

Module Repressurization

Hyperbaric Chamber Pressurization

Emergency Venting

a. Oxygen Supply - The oxygen supply is continuously generated and added to the cabin atmosphere via the process air system. Control of this process is maintained by continuously analyzing the cabin atmosphere for oxygen and adjusting the generation rate based on long term trends of the change in oxygen concentration. The oxygen level will be maintained near the high end of the allowed range to provide greater survival time for the crew. Because of the mass of oxygen present on station fast response times are not necessary. Averaging effects can be utilized to simplify the control system and to reduce the equipment requirements. All oxygen is supplied from the O₂ generation system except for the HAB and repressurization

requirements. The following oxygen requirements are met by on-station generation:

- metabolic
- leakage
- EVA
- airlock losses

Although no oxygen storage is planned for normal station operation, a distribution system is planned for emergency use.

- b. All nitrogen requirements will be supplied from storage. Two types of storage are planned.

A high and low pressure distribution system is shown for the supercritical liquid feed system. The liquid will be boiled off at 870 - 1000 psia and can be distributed to any pressurized module independently of what is being provided to the other volumes. After the pressure is reduced, the line penetrates the bulkhead and is distributed internally throughout the station at a pressure of 100 psia. This distribution system provides low pressure gas to each pressurized volume through the N2 control valve. Since the planned rate of addition is only 3.8 pounds per day, the nitrogen will be added through only one N2 valve for normal operation. This location will be varied on a regular basis to verify that all valves are operational. Nitrogen will be supplied to EVA support which will compress the gas to the desired pressure.

- c. Atmosphere Pressure Control - The PDRD specifies the monitoring and control of the partial pressure and total pressure of the atmosphere components.

- (1) Monitoring will be provided by a small mass spectrometer which will

continuously analyze the cabin atmosphere for the following:

- Oxygen
- Nitrogen
- Carbon Dioxide
- Methane
- Hydrogen

This system provides a direct readout for each gas which is being controlled in the station atmosphere as well as other gases which represent specific hazards to the station. The output signal will be proportional to the amount present and will be used for control of the station atmosphere and for an interface with the caution and warning system.

- (2) Control of the makeup gases to the cabin atmosphere is based on the Major Constituent Analyzer output which will be controlled by the DMS on a continuing basis. A running average will be maintained of the concentration of O2 and N2 and control will be based on the change in the running average. This approach takes advantage of the station capacitance to simplify the control of the makeup gases. Nitrogen and oxygen will be added as previously defined.
- (3) Total pressure will be monitored directly by a sensor and indirectly by summation of the individual component partial pressures as measured by the Major Constituent Analyzer. If the total pressure exceeds the set-points, one and only one of the high pressure relief valves will relieve the pressure to space. This valve will be

rotated through the station relief valves on a regular basis. Pressure control is maintained by makeup through only one valve and relief through only one valve to avoid the situation where the system would be supplying and exhausting simultaneously. Also, by separating the two functions at the opposite end of the station, a pressure wave can be avoided which might trigger a relief valve by adding makeup gas in the same module.

- d. **Module Repressurization** - Repressurization is an action which follows the emergency venting of a module for some reason such as shell penetration, fire or chemical leak. The repressurization system has the capacity to recharge any single module to normal atmospheric pressure once in any 90-day period. This system consists of high pressure nitrogen and high pressure oxygen tanks permanently maintained on orbit with the station. These tanks are kept at 3000 psia and are external to the station. Both gases are connected to the internal distribution system for O₂ and N₂ by penetration through both the U.S. HAB and Lab modules. Pending further direction it has been assumed that the repressurization will take one hour for the full size module.
- e. **Hyperbaric Chamber Repressurization** - This gas supply is included in the high pressure storage previously described in the module repressurization system. The hyperbaric chamber

must be rapidly pressurized to 6 atmospheres in a life threatening situation. this gas will be transmitted via the internal distribution system.

f. **Emergency Venting :**

The ACS provides:

- Emergency release of the module atmosphere
- Negative pressure relief
- Pressure Equalization

in addition to the positive pressure relief previously described.

- (1) Emergency release of the module atmosphere is provided by valves mounted on the bulkhead in each pressurized volume. These valves can be operated either manually or automatically and will dump the module atmosphere in less than five minutes.
 - (2) Negative pressure relief is required during launch or reentry should a module have to be returned to earth. A negative pressure relief valve is installed on the bulkhead in each pressurized volume.
 - (3) Pressure equalization valves are included on each hatch and are used to equalize pressure between pressurized volumes prior to opening the hatch.
- g. **System Control** - All control of the ACS is through the Standard Data Processor (SDP) in the DMS. All valves are automatic/manual and can be actuated from the SDP. Key valves such as the emergency vent

and the O₂/N₂ control valves can be activated by an astronaut in EEU.

6.3.2.11 Atmosphere Revitalization System (ARS)

The table presented below provides in summary of ARS functions and corresponding equipment.

FUNCTION	EQUIPMENT
O ₂ Supply	KOH Static Feed -Water electrolysis
CO ₂ Reduction	-Bosch
CO ₂ Removal	-Four bed molecular Sieve
Trace Contaminant Control	-Charcoal filters -Specific sorbents -Catalytic oxidizer
Contamination Monitor	Chromatograph/ Mass Spectrometer CO monitor Particle counter
Odor Control	-Selective Adsorbers

6.3.2.11.1 Static Feed Water Electrolysis

The subsystem consists of three main components: an electromechanical module, a Coolant Control Assembly (CCA) and a Pressure Controller. The CCA and Pressure Controller are special components developed for use with a static feed system.

The module consists of a series of individual electrochemical cells stacked fluidically in parallel and connected electrically in series to form the Static Feed Water

Electrolysis Module (SFWEM). Oxygen and hydrogen are generated in the SFWEM from water supplied by the water supply tank.

a. The CCA supplies a constant flow of controlled, variable temperature liquid coolant to the SFWEM, (1) proportions the coolant flow between a bypass and a liquid/liquid heat exchanger, and (2) accommodates temperature induced volume changes in the coolant.

b. The Pressure Controller maintains the absolute pressure of the subsystem, (1) controls the pressure differential required to establish and maintain liquid/gas interfaces within the individual cells, and (2) controls pressurization and depressurization of the subsystem during mode transitions (e.g., start-ups and shutdowns).

As electrical power is supplied to the electrodes, water is electrolyzed from the cell matrix creating an electrolyte concentration gradient between the water feed cavity electrolyte and the electrolyte in the cell matrix. Water vapor diffuses from the water feed matrix into the cell matrix due to this gradient. Consumption of water from the water feed cavity results in its static replenishment from an external water supply tank,

6.3.2.11.2 Carbon Dioxide Removal and Collection

Approximately 17.6 pounds of carbon dioxide (CO₂) are generated per crew day. A closed environment such as a Space Station will reflect this added CO₂ as increased partial pressure at a rate dependent on the face value. Active CO₂ removal subsystems must be employed to maintain partial pressure within tolerable limits, presently set at a maximum of 3 mm Hg.

6.3.2.11.3 Molecular Sieve

CO₂ removal from the cabin atmosphere is accomplished by the preferential adsorption of CO₂ by a material classified as zeolites and referred to as molecular sieves because of their affinity to remove molecules of a given size (i.e., 4 Angstrom size molecules).

Cabin air is chilled and the condensed water is removed. The air is then pumped at a rate of about 8.4x10⁻³ m³/min. (30 ft³/min) through the molecular sieve beds on side A. The 13X bed, is designed to preferentially remove moisture from the incoming air, allowing CO₂ to be adsorbed on the 5A bed downstream. CO₂ depleted air is then heated and passed through the 13X bed on side B to remove adsorbed moisture and prepare the bed for use as a desiccant. The 5A bed containing adsorbed CO₂ is isolated from the air stream and regenerated by heating and pumping of the evolving CO₂ gas by two stage vacuum pumps. The initial ullage inside side B5A bed, consisting of oxygen and nitrogen, is pumped back to the cabin. When the absolute pressure in the bed is sufficiently low, the relatively pure (90-95 percent) CO₂ is pumped into a storage tank. The collected CO₂ will be used to feed the carbon dioxide reduction subsystem.

d. Carbon Dioxide Reduction

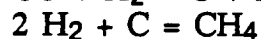
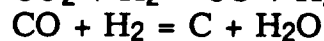
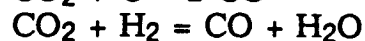
The Bosch concept is the current baseline process for reducing CO₂.

The Bosch reaction occurs in the range 800 to 1000K (980 to 1340F) in the presence of an iron catalyst. Carbon dioxide combines with H₂ and produces carbon and water vapor as indicated in the overall reaction:



One mole of CO₂ combines with two moles of H₂ to form one mole of carbon and two moles of water vapor. In practice, single pass efficiencies through the Bosch

reactor are less than 10 percent. Complete conversion is obtained by recycling the process gases with continuous deposition of carbon and removal of water vapor. The recycled gas mixture contains CO₂, H₂ water vapor, carbon monoxide (CO) and methane (CH₄). These components are formed by intermediate reactions, such as:



An equilibrium condition for the gas mixture is reached based on the specific operating temperatures, pressures, and relative proportions of the primary reactants, CO₂ and H₂.

The BCRS operation is described herein. Gases are continuously circulated through the recycle loop by a compressor. The gases leaving the compressor pass through the regenerative heat exchanger/reactor combination. The gases are preheated in the regenerative heat exchanger prior to entering the reactor. Within the reactor CO₂ and H₂ react over an iron catalyst in the volumetric ratio of 2:1 (H₂:CO₂) to form carbon and water vapor. The recycle gases, partially depleted in CO₂ and H₂ leave the reactor at a temperature near 9220K (12000F) to exchange heat with the incoming gases in the regenerative heat exchanger. The mixture then flows through the valves to a condensor/separator where the water vapor is condensed separated, and collected. The recycle loop gas mixture then returns to the compressor.

The feed gases (H₂ and CO₂) are added to the loop upstream of the compressor. This allows the feed gas pressure to remain at a minimum. For practical applications the ratio of recycled gas flow rate to feed gas flow rate is in the range of about 15-20 to

1, indicating that conversion efficiency per pass through the reactor is about 6 percent.

6.3.2.11.4 Trace Contaminant Control

Trace contaminants are controlled by the use of specific sorbents and a non regenerable carbon bed which is replaced every 90 days and a high temperature catalytic oxidizer. Additional control is provided by module leakage of atmosphere to space and condensation of organics in the humidity control system. Specific sorbents will be used to control ammonia, carbon monoxide and hydrogen (low temperature catalyst) and acid gases.

6.3.2.11.5 Atmospheric Monitoring

Two different problems exist for atmospheric monitoring. They are: 1) Trace contaminant analysis and 2) major constituent analysis. Although these two functions may be combined in one instrument, two separate analytical systems will be provided to meet these needs.

6.3.2.11.6 Trace Contaminant Analysis

The trace contaminant analysis baseline is currently a gas chromatograph mass spectrometer (GCMS) combination analytical system. This system is an accepted analytical technique for separation and analysis of complex mixtures of organic compounds. The GCMS provides good mixture separation and positive identification capability by utilizing the strengths of each analytical technique. By careful evaluation of the expected contaminants, the gas chromatograph (GC) can be specified to provide separation of organic compounds into specific categories such as alcohols, aldehydes and ethers. Once separated, the mass spectrometer (MS) performs the analysis to determine the concentrations present in the atmosphere. This equipment can provide analytical ca-

pability for any number of organic compounds. The only drawback being separation time in the GC and relative complexity of the MS to provide the expanded analytical capability. One advantage provided by the Data Management System is the library for unknowns can be ground based. If an unknown is detected, the information from the GCMS can be transmitted to the ground and a detailed evaluation conducted there utilizing the expertise of ground based analytical chemist. The station equipment can continue the scheduled analysis and extensive on-board computer capacity is not required to maintain an analytical chemical file. The biggest drawback to performing extensive analyses of this type is speed. The expected analytical cycle with current technology is 60-90 minutes.

This slow analytical time does not represent a major risk to the crew. Sources of contaminants will be primarily metabolic and off gassing of chemicals from the various plastics and coatings used on the station.

There is no reason to expect any of these chemical concentrations to suddenly increase. Upset conditions such as a chemical spill or a laboratory operational problem can be countered by providing an override capability in that area for the GCMS or by using less sophisticated but faster response time analytical techniques such as color change "sniffer" tubes for specific chemicals. The baseline for the GCMS is one unit in each of the Habitat Modules. This redundancy means that normal analytical capability exists even if one unit should be committed to a specific analytical problem. The capability to provide specific component monitoring capability on an emergency basis does not exist in the present design and would add to the complexity of the GCMS.

6.3.2.11.7 Major Constituent Analysis

The preferred technology, gas analyzer mass spectrometer (GAMS) was developed for Skylab and monitors hydrogen, water vapor, nitrogen, oxygen, carbon dioxide and methane.

6.3.2.12 Water Recovery and Management System (WRMS)

The Space Station Water Recovery and Management System (WRMS) shall accommodate the collection, processing, and dispensing of water to meet evolving Space Station crew and other potential needs. Pretreatment of waste water to prevent chemical breakdown and microbial growth prior to processing shall be provided. Post-treatment systems and a monitoring system to ensure proper water quality shall be provided to control and monitor contaminants prior to water use. Potable hygiene, and wash water shall be provided.

6.3.2.12.1 Water Collection

Water collection is accomplished by air transport through equipment to air/water separators or by receiving a water stream from the associated subsystem. Water for potable use is collected from the following systems humidity control and CO₂ reduction system. Water for hygiene use is collected from the following systems: 1) hygiene and hand wash station, 2) waste potable water, 3) galley, 4) dishwasher, 5) shower, 6) laundry and 7) processed urine.

6.3.2.12.2 Potable Water

Potable water is generally described as that which is "suitable for drinking." Space Station potable water is used to supply both drinking requirements and the preparation of food. Therefore, potable

water is to be considered that which will finally be ingested by the crew.

- a. Potable Water Sources – Potable water will come from three sources: condensate from the atmosphere, CO₂ reduction water, and resupply.
- b. Potable Water Processing – There were three processes under consideration for potable water processing. The three processes were: hyperfiltration, multifiltration and reverse osmosis.

Multifiltration is recommended for potable water processing.

6.3.2.12.3 Multifiltration

The multifiltration treatment method consists of four stages of treatment. The first is a roughing filter to remove large particulate matter. The second stage is an adsorption bed, which holds a specially selected granular activated carbon in which the pore structure has been controlled to include a wide range of pore sizes which can capture and retain molecules of the lightest charged organic material. The third stage is an ion exchange state, where a specially selected blend of deionizing resins. The last stage of treatment is a sterilization filter.

After processing, potable water will be checked by an on-line water quality monitor that will be discussed later. Then water that passes is transferred to storage and biological testing.

6.3.2.12.4 Potable Water Storage

Potable water that has been recovered and treated to meet use requirements is to be stored in tanks that can be assured to be maintained biologically acceptable.

After passing the on-line water quality monitoring tests a potable water storage tank is filled. When that tank is full a sample is drawn and tested for bacteria prior to the use of the water.

With one potable water processor in each module and two "clean" potable water tanks in each module a fill, test, stand by, use scenario can be implemented. This is accomplished by starting with module one having one tank filling and the other in standby mode and module two having one tank in use and the other being tested. When the test tank finishes and passes the bacteriological test it becomes standby, the fill tank goes to test when full, the use tank goes to fill when empty and the standby becomes the use. The cycle continues with the original use tank eventually becoming the use tank again.

6.3.2.12.5 Hygiene Water

Hygiene water is water that is processed to meet standards as required and may come in contact with crewmembers. Hygiene water is also considered acceptable for use as a source for electrolysis or other subsystems that may require purified water. Wash water will be added to the hygiene water eliminating the need for a separate wash water system.

6.3.2.12.5.1 Hygiene Water Sources

Hygiene water will come from the following sources: hygiene and hand wash stations, waste potable water, galley, dishwasher, shower, laundry, processed urine, excess potable water production, and resupply.

6.3.2.12.5.2 Hygiene Water Processing

There were three processes considered for hygiene water processing. The three processes were the same three as for potable water processing; hyperfiltration, multi-

filtration, and reverse osmosis. Multifiltration is recommended for hygiene water processing.

6.3.2.12.5.3 Hygiene Water Storage and Supply

Recovered hygiene water is stored in two tanks. These tanks are used to supply water used for O₂ generation, Extravehicular Mobility Unit (EMU) requirements, urine flush, shower, hygiene and hand wash, dish washer, and laundry.

Processed Hygiene water is monitored by a water quality monitor (WQM) and iodine test unit. Failure to meet specification in pH, conductivity, Total Organic Carbon (TOC), or iodine, will cause the water to be returned to the waste holding tank for reprocessing or to before the microbial check valve for iodine dosing.

6.3.2.12.6 Urine Treatment

Urine is received from the Waste Management System for water recovery. Three methods of water recovery from urine were considered. These methods were: air evaporation (wick evaporation), Thermo-electric integrated Membrane Evaporation System (TIMES), and Vapor Compression Distillation (VCD). Air evaporation is recommended for water recovery from urine. After water has been recovered from the urine the recovered water is transferred to the hygiene water processing system for further processing and the residual brine is transferred to the Waste Management System for storage and final disposal.

6.3.2.12.6.1 Pretreatment

Chemical pretreatment is necessary to stabilize the urine, preventing enzymic breakdown to ammonia, and providing continuing inhibition of bacterial growth.

A recent study by NASA includes data on three methods that have evolved in the last several years. In all methods, sulfuric acid is used to lower pH to between 2 and 4 which stabilizes ammonia as ammonia sulfate. Along with sulfuric acid, a biologically active chemical is added to control bacterial growth.

The oxone formulation proved to be the best long-term urine stabilizer a 34 day test with oxone added at varying levels shows a complete control of bacterial activity with 5 milligrams oxone per cc urine. Additional test work was conducted on the foaming characteristics of pretreated urine. Some urine processing subsystems operate at reduced pressure, causing dissolved gas products to evolve, forming a foam. As in the case of vacuum compression/distillation concept, excessive foam would cause carry over of undesirable materials into the product water condensate. Tests showed that control of foaming could be accomplished with small doses of antifoam. Long duration testing must be conducted on specific waste recovery subsystems with pretreated urine to verify total compatibility of the chemical additives with the operation equipment.

6.3.2.12.6.2 Air Evaporation (Wick Evaporation)

Closed Cycle Air Evaporation. This concept uses a recycled gas atmosphere to evaporate water from a wicking material saturated with pretreated waste water. The atmosphere is the same as cabin atmosphere and is contained in a closed system to preclude direct contamination of the cabin. When solids have built up on the wicking material causing reduced efficiency, the wick is allowed to dry, the wick replaced, and flow directed to the fresh wick bed. The saturated dry wick is stored for disposal.

Initial concepts used heating and cooling, with minor heat recovery in the loops. Excellent water is produced by this method, but additional development has not been conducted. Regenerative heat exchange can be configured into this concept using heat pumps to reclaim heat from the air stream. this reclamation of heat reduces the power required by the Air evap Unit. There are potential further savings by scavenging heat from the thermal control system instead of reclaiming heat internal to the system.

6.3.2.12.6.3 Water Quality Monitoring (WQM)

Water quality is monitored on a continuous basis to determine suitability of recovered water for reuse. Overall water quality can be determined by measuring pH, conductivity, total organic carbon (TOC) and bacterial content.

In addition to chemical analysis is the requirement for determination of microbial level. No subsystem has been developed to date to automatically measure microbial activity.

a. Water Quality Monitor 1 - An automated WQM has been tested by NASA and although the unit does work, the maintenance and standardization of the unit under continuous use is found excessive.

A peristaltic pump delivers the sample, supplied at 5 psia, two reagents and periodically, two standardizing solutions to the sensing manifold which contains the flow through sensors for conductivity, TOC, pH, and NH₃. Prior to entering the peristaltic pump, the sample is divided into two streams, the acidic stream and the basic stream.

The TOC and conductivity measurements are made on the subsystem acidic stream. The sample is pumped directly through the conductivity sensor. This sensor consists of two 0.24 inch lengths of 0.03 inch I.D. thin walled platinum tubing, which are epoxy cast into an acrylic block. Sample fluids flow in series through the platinum tubes, which act as conductivity electrodes. After the sample exits the conductivity sensor, a reagent consisting of sulfuric acid and an oxidizing agent (potassium monopersulfate) is added. The acid reagent converts all the inorganic carbon (carbonates, etc.) in the sample to free dissolved CO_2 . In the stripper, the dissolved CO_2 diffuses through a membrane to the basic stream where the CO_2 is fixed as carbonate. After removal of the inorganic carbon, oxidation of organic carbon is accomplished by exposing the sample with oxidizing agent to ultraviolet light. The TOC measurement is determined by a CO_2 sensor mounted on the sensing manifold. The CO_2 sensor consists of a capillary pH electrode, which is in contact with an aqueous sodium bicarbonate electrolyte. The electrolyte and capillary are separated from the ultraviolet irradiated TOC sample by a silicone rubber membrane. Equilibrium of the sample CO_2 with the reservoir across the membrane results in an electrode output proportional to the logarithm of the CO_2 concentration. The CO_2 concentration measured, directly correlates to the TOC in the water sample.

The pH and NH_3 measurements are made on the WQM basic stream. A capillary pH electrode, geometrically identical to the CO_2 sensor but without a membrane, is used for the pH sensor. After the sample exits the pH sensor, it is combined with an alkaline (sodium hydroxide) solution and thoroughly mixed by a magnetic mixer unit. The mixer ensures complete conversion of NH_4^+ to free dissolved NH_3 prior

to making the ammonia measurement. The mixed basic sample is then routed through the sensor manifold to the NH_3 sensor. Construction of the NH_3 sensor is mechanically identical to the CO_2 sensor but uses an ammonium chloride electrolyte and a microporous Teflon membrane. The alkaline solution is then used as the CO_2 stripping reagent for TOC sensing as previously mentioned. After passing through the stripper, the basic sample stream is joined with the acidic sample stream downstream of the sensors and is sent to waste water treatment.

The subsystem was designed for manual or periodic automatic calibration using two standardizing solutions. During calibration, the standardizing solutions take the place of the water sample in the input stream. All four measurement parameters can be calibrated with the two standardizing solutions.

b. Water Quality Monitor 2 - This Water Quality Monitoring System consists of two commercially available water quality monitors. One senses the level of Total Organic Carbons in the water and the other senses pH, conductance, and six specific ions. Samples are automatically taken every 5-10 minutes from each of four sample ports. A sample from each port is injected into each analysis cell. After analysis (3-5 minutes per sample) the samples are returned to waste water storage. One of the advantages of this system is that no chemicals are added to the water and the spent samples can be returned to the water supply.

These two water quality monitors measure certain water quality parameters directly such as pH, conductance, and specific ion contents. Microbial growth will be measured, by incubation of samples, prior to use as potable water and in conjunction with use as hygiene water. Other param-

ters are inferred from changes in Total Organic Carbon, pH, and conductance. Periodic checks on the inferences made by the Water Quality Monitors would be made by crew members on a periodic basis using the characterization equipment available in the laboratory modules and returning samples to earth for complete analysis.

6.3.2.12.6.4 Crew and Equipment Wash and Utilities

Provision for washing and personal hygiene are supplied by the module outfitters.

6.3.2.12.6.5 Safe Haven

For safe haven, water will be supplied by varying methods all requiring power, thermal rejection and DMS. The first mode is normal operation with a suspension of 48 hour holds on potable water. In the event that a unit fails it will be repaired and operation continued. The following assumptions are made for this mode of operation: Potable and hygiene water can be supplied from either hygiene or potable water processors; and Urine can only be processed in a Phase change processor. In this case the potable and hygiene processors back each other up and redundant urine processors are installed for failure tolerance in both normal operation and safe haven. To accomplish safe haven it is necessary that a potable and hygiene system each be installed in at least two separate pressurized volumes and that there be two urine processors in each pressurized volume containing waste management facilities.

6.3.2.12.6.6 Man-Tended

At the present time the man-tended water management requirements are to be supplied by the Space Shuttle during tending

and there are no further ECLSS/water requirements for untended modes.

6.3.3 Waste Management Systems (WMS)

The Space Station Waste Management System performs the following functions: 1)collection urine, feces, and vomitus; 2)collection and processing of trash; 3)general housekeeping; and 4)storage of wastes for return to Earth and/or final disposal.

6.3.3.1 Urine Collection

Urine collection is to be accomplished in a manner similar to the methods presently used on Space Shuttle. Once the urine is separated from the air entrainment it is delivered to the Water Recovery and Management System (WRMS) for water recovery. After reclamation of water from the urine the resultant brine and/or solids are delivered to the WMS for waste storage and return to disposal. Present recommendation is for two urinal commode combinations in two separate pressurized volumes.

6.3.3.2 Feces and Vomitus Collection and Processing

Feces and vomitus will be collected from the crew members in an as Earth-like as possible manner by air transport and subsequently processed by the same unit. Boeing has four subcontractors investigating four different collection and processing options. The subcontractors and the options they are investigating are as follows:

- a. Fairchild-Republic - Compactor with replaceable cartridges
- b. General Electric - Bag collection with air drying

c. Hamilton Standards Division - Biodegradation cup

d. Teledyne Brown Engineering - Bag collection with mechanical transfer

The General Electric concept has been chosen for the Space Station commode/urinal.

This concept utilizes current shuttle technology in combination with design improvements dictated by crewmembers comments and extensive testing. It is an integrated system which is based on proven components and techniques. Proposed enhancements include increased capacity, containerization, and increased odor/bacteria filter capacity. Performance improvements are air drying and assembly replacement of critical components.

Additional capacity can be derived by enlarging the shuttle commode container within the proposed envelope. Compaction methodology within the holding tank is presently under evaluation. Capacity is also increased by the removability of the container.

The basic requirement for containerization of waste products is that the container be non-permeable to microbes. In order to effectively provide microbial protection and facilitate crew servicing, a non-woven, hydrophobic, soft bay system is proposed. This concept offers waste removal and handling when incorporated with a split, hinged commode tank.

Redundancy is provided within the commode/urinal unit for comfort and convenience of crew members. These are dual fan separator units which can be operated singularly or in parallel to provide commode/urinal air flow. These fan separator units are identical and replaceable in space by crewmembers

A single urinal hose is provided with the commode/urinal unit which provides redundancy in that it can be plugged into receptacles which are internally plumbed to either one of the fan separators. Therefore, if a problem exists with one separator, the other can be selected by connecting to the alternate receptacle. Redundancy is provided for urinal cups in that each crewmember has his own individual unit and spares provided should they be needed.

The commode waste collector is a replaceable which provides microbial integrity during the removal cycle. The commode waste collector is replaced periodically as the need exists for capacity.

Dual odor/bacteria filters are provided. One filter is in the air discharge from each fan separator which protects the crew from noxious odors and provides backup for the commode bacteria filters.

Operation of the commode/urinal is similar to the present Shuttle commode, except for simplification and the removable bag container. Since air drying is utilized, the valving is greatly simplified and certain switching can be eliminated. Fecal air drying with a small air fan which operates continuously is provided, eliminating overboard vacuum venting. Containerization is accomplished by a removable bag. In operation the bag container would be capped on top and bottom when removed. The entire container would be then placed into a trash compactor and a replacement installed into the commode. The urine system is enhanced by newly designed individual cups which provide optimum air flow, separation and last drop collection.

6.3.3.3 Collection and Processing of Trash

Trash collection is presently considered to be bag collection with continuous air flow for drying and containing the trash in the unit when the unit is opened. Periodically the bags are removed and placed in the trash compactor. The compactor will reduce the volume with a compaction ratio of approximately 20:1. Trash collectors are allocated to all modules except the logistics module. A trash compactor is in the Habitat Module.

6.3.3.4 General Housekeeping

Equipment for housekeeping will include wet/dry vacuum cleaners, wipes, biocide, and cleaners. These items will be used in every day cleaning of the Space Station, including vacuuming of air intake filters at regular periods. The vacuum cleaner is to be designed as a wet/dry vacuum cleaner to assist in containing and cleaning up on liquid spills in the Space Station. Vacuum cleaners will be allocated to both U.S. Modules with the remainder of the items to be allocated to all modules except the Logistics Module.

6.3.3.5 Waste Storage and Disposal

At the present time, all nonrecyclable wastes are to be stored for return to Earth. This storage will be in the Logistics Module in solid, liquid and gas form. The solids will be stored in compacted form in lockers. Liquids and gases will be stored in appropriately designed tanks.

There are two possibilities to minimize return weights and volumes. One possibility is the use of waste fluids in the Space Station propulsion system to augment the thrusters thereby minimizing quantities stored and returned to Earth. The other option is the destructive reentry of wastes

both solid and liquid to eliminate waste return.

6.3.3.6 Safe Haven

Safe haven waste management will be provided in two modes. The first mode is normal operation and will depend on availability of power, thermal rejection and access to the normal waste management system. The second mode will be the emergency backup mode currently used on the Space Shuttle for emergency back up with some modifications possible.

6.3.3.7 Man-Tended

At the present time, man-tended waste management requirements are to be supplied by the Space Shuttle during tending and there are no further requirements for ECLSS untended modes.

6.3.4 Fire Detection and Suppression

The Fire Detection and Suppression (FDS) subsystem provides the sensors for detecting a fire and the suppressants to extinguish the fire. Each module has its own FDS subsystem that detects the presence and location of a fire condition within the module. The output of each module FDS is inputted to the module data bus to provide an annunciated and visual alarm to all Space Station modules. The fire suppressant system is designed for manual or automatic operation as determined by the crew. The FDS subsystem includes smoke/fire sensors, fire suppressant extinguishers and distribution, and emergency breathing packs.

FDS will be supplied to each powered rack and to each storage rack containing combustible material. Fire Detection (FD) sensors are provided that will detect a fire in all stages of combustion to give early

warning of fire buildup conditions as well as actual fires. Ionization and thermal sensors are located in each rack to identify the rack in which a fire occurs. Ionization sensors are located in the Module Temperature and Humidity Control and Avionics Cooling air return ducts that detect the presence of aerosols from a group of racks. Infrared sensors monitor the module aisles for fires. Both the thermal and ionization detectors require an air flow rate through each rack to be monitored.

The Fire Suppression (FS) system consists of a centralized CO₂ storage tank with distribution to each rack through valves activated by the FDS controller. The rack valves can be operated automatically or by the crew through the Module Caution and Warning system. Each automatic operation is timed to release a predetermined amount of CO₂. The capacity of the tank is 50 lbs of CO₂. A typical fire in a rack would require approximately 0.5 lbs of CO₂ per 10 ft³ of free air space to be suppressed.

The status of the fire detection sensors is monitored by the FDS controller through the rack Multiplexer/Demultiplexer (MDM). When a rack fire indication is received, commands are sent to the rack that shut off the Avionics air supply and return to the rack, energizes the CO₂ release valve and turns on a light on the rack FDS Panel. The FDS Controller also sends a signal to the Module Caution and Warning System to alert the crew that a fire exists in the module/rack location.

Portable CO₂ fire extinguishers are available for local suppression in each Space Station element. These extinguishers are sized for 5 lbs of CO₂. Each rack provides an access port for manual insertion of CO₂. Emergency breathing packs are provided in all Space Station elements to allow the crew sufficient time to leave an

area in which a fire occurs. These packs are sized for 12 minutes of normal breathing.

6.4 Laboratory Module Outfitting

"U.S. Laboratory Outfitting" in this section will be limited to discussing general configurations and unique areas. Obtained data is continuous in Boeing document D483-50022-3, Rev C (DR02) October 31, 1986. Further, Section 3.0 of this document contains a description of "Customer Accommodations".

6.4.1 Configuration

The USL configuration is driven by a wide range of Materials Processing Science and Life Science user requirements which vary greatly both between potential USL users as well as between station evolutionary scenarios. The capability and requirements of the USL experiments typify 1995 era operation. The equipment compliment in the point design is driven by the selection of a set of experiments to be flown.

6.4.2 USL Module

6.4.2.1 Design Approach

The envelope dimensions of the USL are shown in Figure 6.4.2.1-1. The internal architecture of the USL will incorporate a horizontal orientation with four (4) longitudinal utility trays, Figure 6.4.2.1-2, and locations for forty-four (44) standard double racks, Figure 6.4.2.1-3.

The next step was to further refine the racks and payload containers which optimally fit into the chosen internal architecture. Defining rack requirements was a key element in determining the preferred internal arrangement, but these basic building blocks are even more important in determining utility layouts,

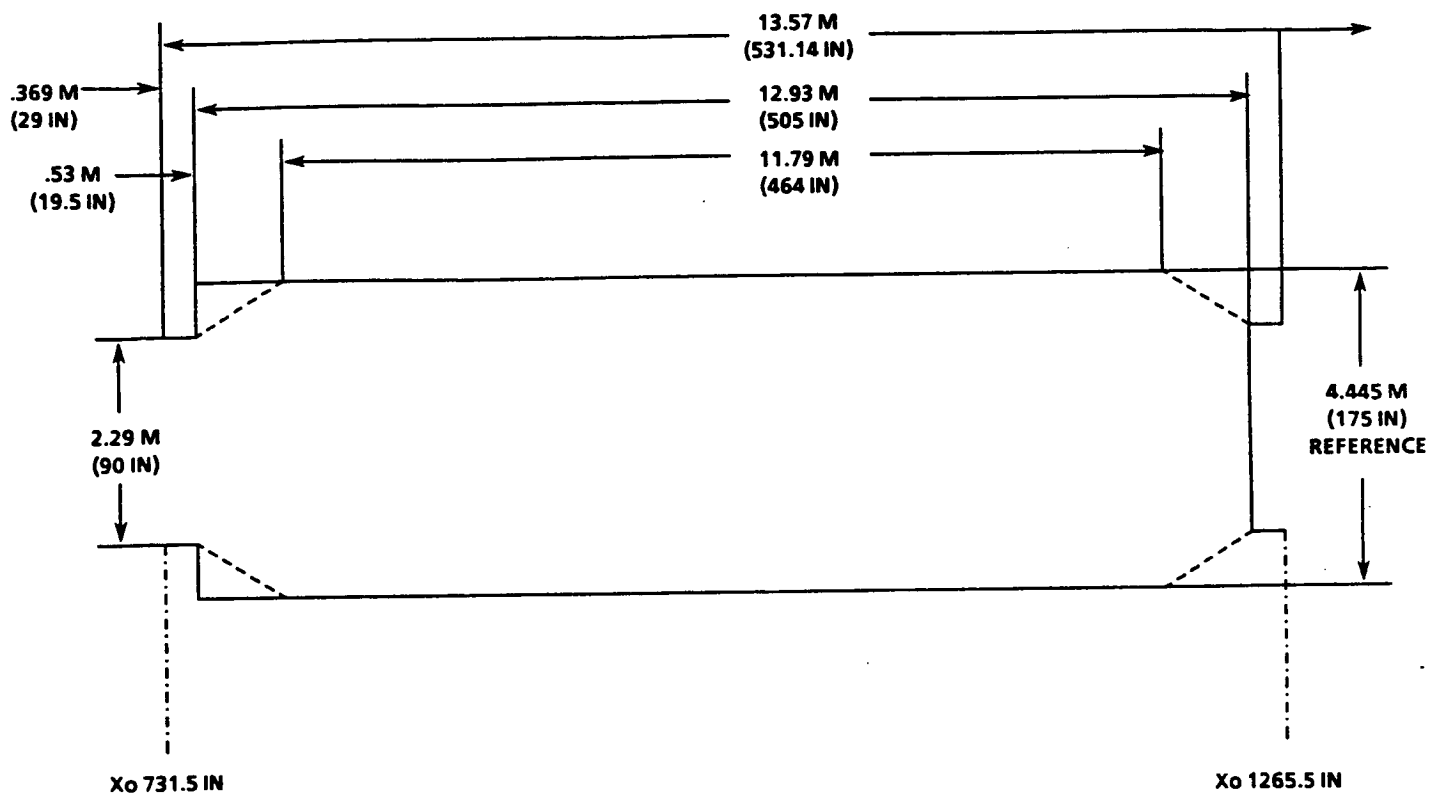


FIGURE 6.4.2.1-1 COMMON MODULE ENVELOPE DIMENSIONS

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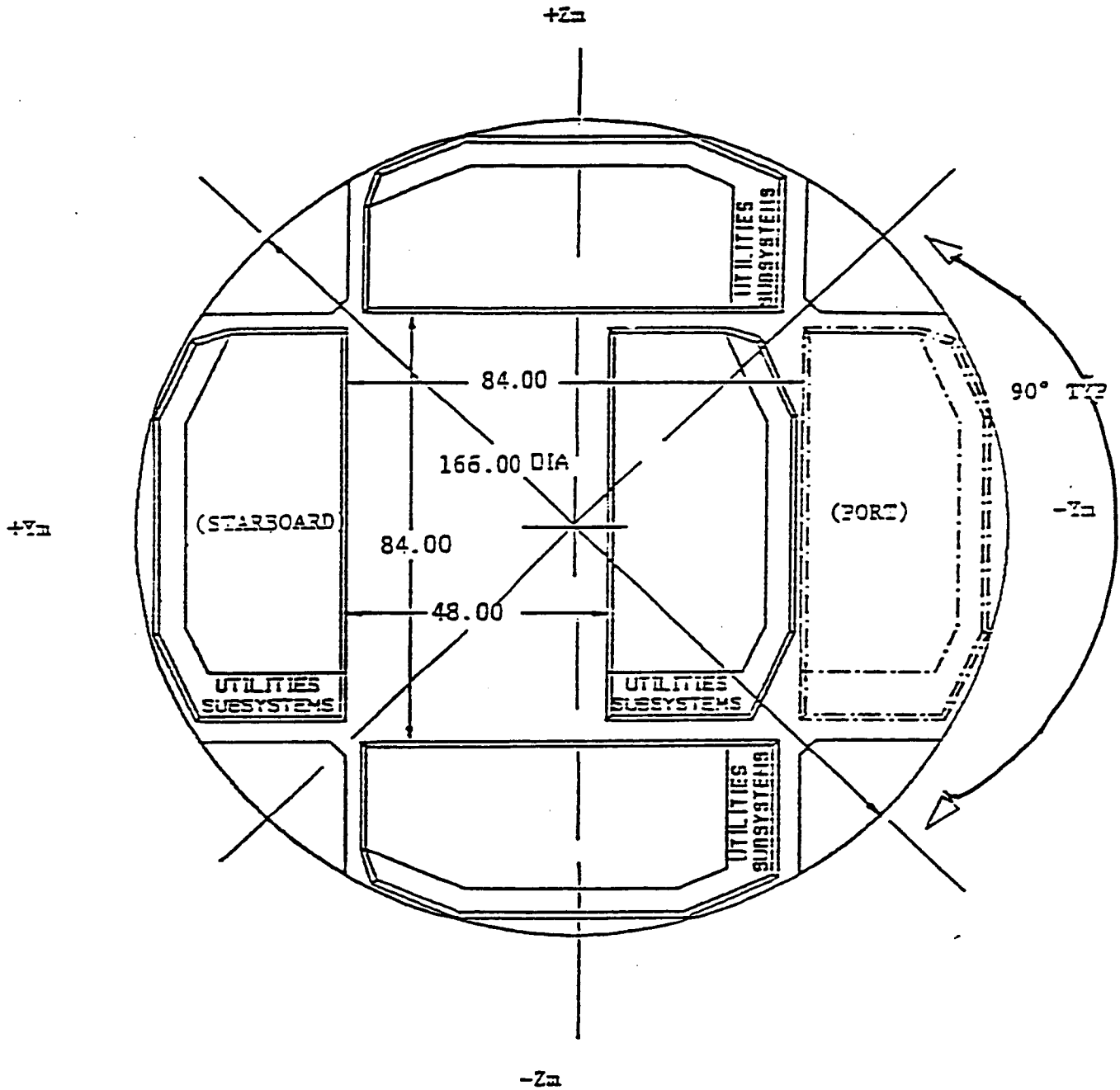


FIGURE 6.4.2.1-2 SYMMETRIC 4 STANDOFF CONFIGURATION

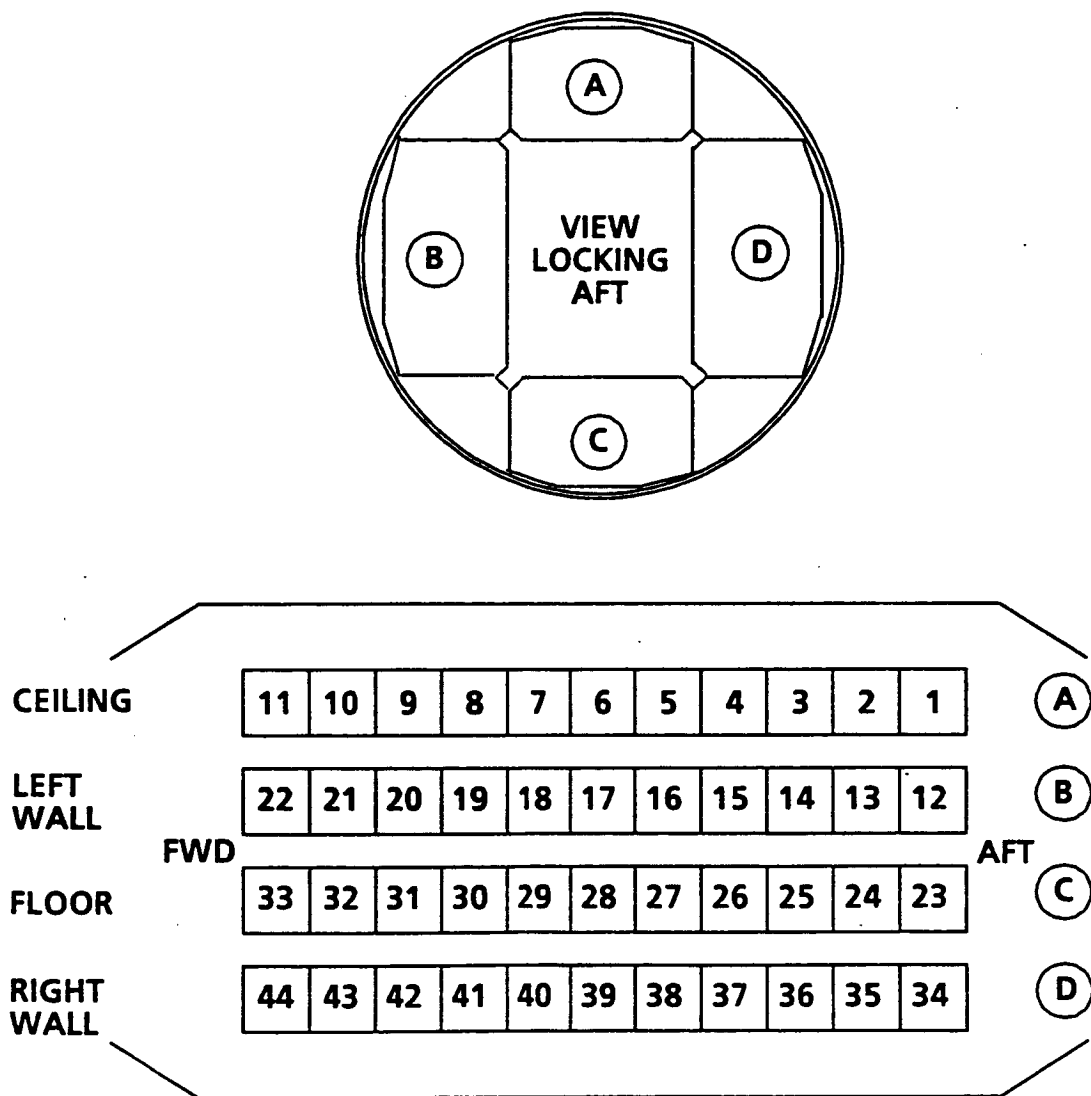


FIGURE 6.4.2.1-3 STANDARD RACK LOCATIONS

secondary structure definition, and the other lower level module outfitting definition.

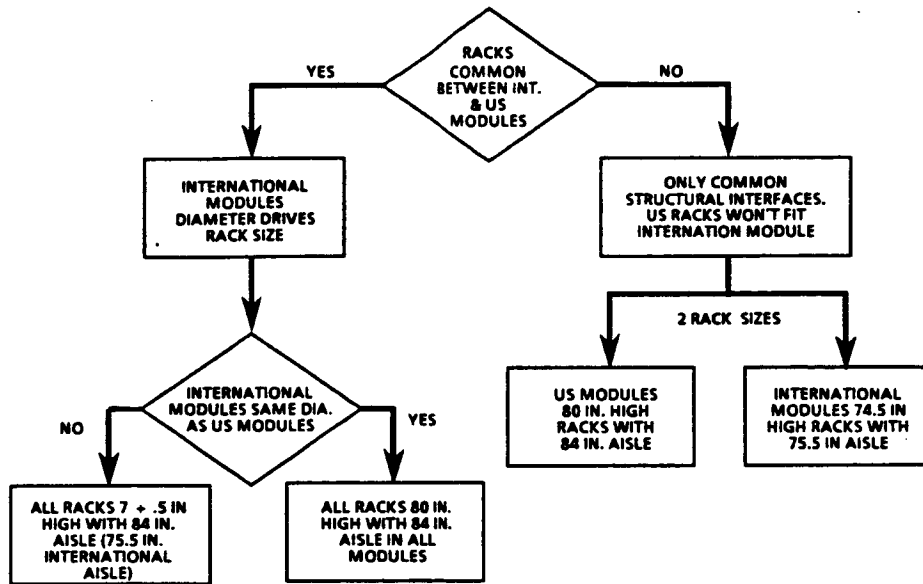
The racks must be responsive to the user requirements of equipment mass, height, width, and depth; and they must fit within the prescribed envelopes. User payload equipment mass will have a 350 kg (771.6 lb) single rack limit and a 700 kg (1543.2 lb) double rack limit for ground and launch operations. The mass can be increased on-orbit to the limit afforded by the rack user volume. Incorporation of EIA Standard RS-310 (Racks, Panels, and Associated Equipment), will enable us to accommodate a majority of rack mounted equipment. The experiment data base shows that a 914.4mm (36 in) deep rack with 152.4mm (6 in) for utility distribution and secondary structure (thus 762 mm (30 in) left for payload) and front panel protrusions will capture 90 percent of all rack mounted equipment depths. Rack interchangeability with the international modules is a requirement, but this requirement should be applied on a functional basis. The international technical groundrules state the requirement for interchangeable ORUs and payload elements. Figure 6.4.2.1-4 shows a methodology for defining rack envelope dimensions, as a function of degree of commonality. This methodology was used to baseline the envelopes shown in Figure 6.4.2.1-5. These envelopes are responsive to hatch size, payload requirements, internal architecture, and the other constraints mentioned above. These rack envelopes are used in following configuration descriptions and are also the subject of the following comments and concerns:

- a. ESA and Japan module diameters are smaller than the US module diameters. This drives the requirement for the small 1892.3mm (74.5 in)

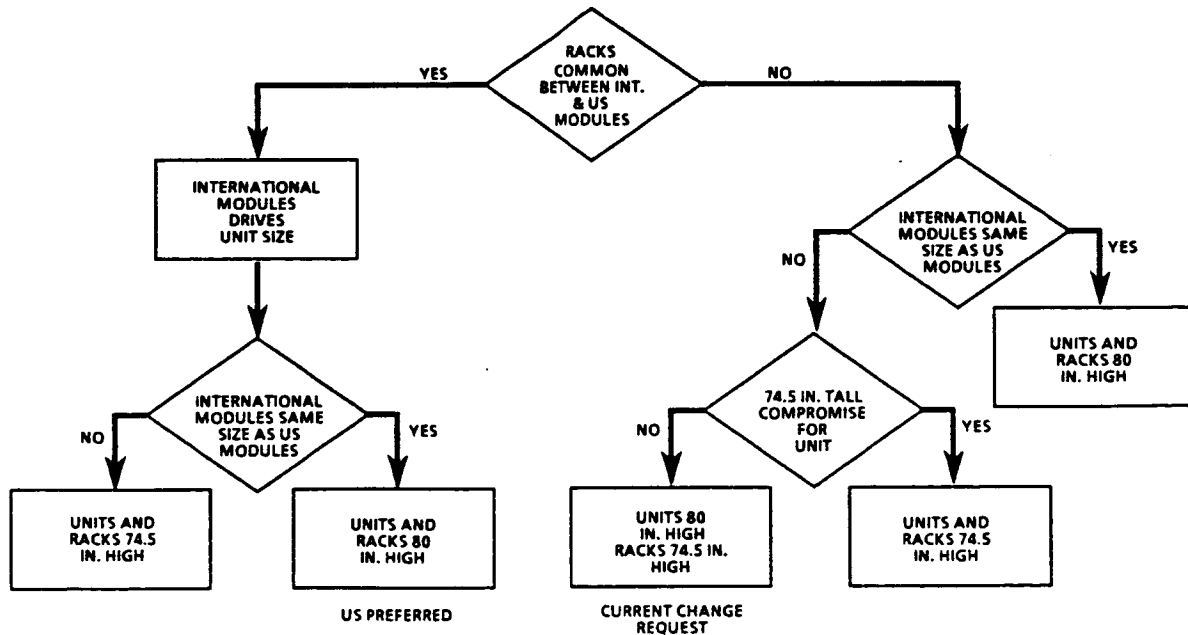
high rack for intermodule interchangeability. A complete level A trade study, comparing the impact of requiring that all module diameters be the same as the current US diameter vs. the impact of the smaller standard equipment rack, has not been done. Rack user volume and capture percentage impact, along with logistics volume impact, are prime concerns.

- b. Given the premise that the 1892.3mm (74.5 in) high rack is required, then all racks and "functional units" should be the same height. The comfort impact for the anthropomorphic units should be traded against the impact of two rack/unit sizes on the logistics module and on the utility run/standoffs of the HAB and USL modules.
- c. Given the premise that two module diameters are required and two rack/unit heights are required, then:
 - (1) These functional units should be interchangeable between the habitation and U. S. Logistics Modules, using mounting interfaces common or compatible with the standard rack mounting accommodations.
 - (2) Non-anthropomorphic racks that are not required to be interchangeable between the US, ESA, and Japan modules may comply with the 2032 mm (80 in) high functional unit envelope, instead of the 1892.3mm (74.5 in) high rack envelope. USL module subsystems, unique sub-

STANDARD RACK SIZE

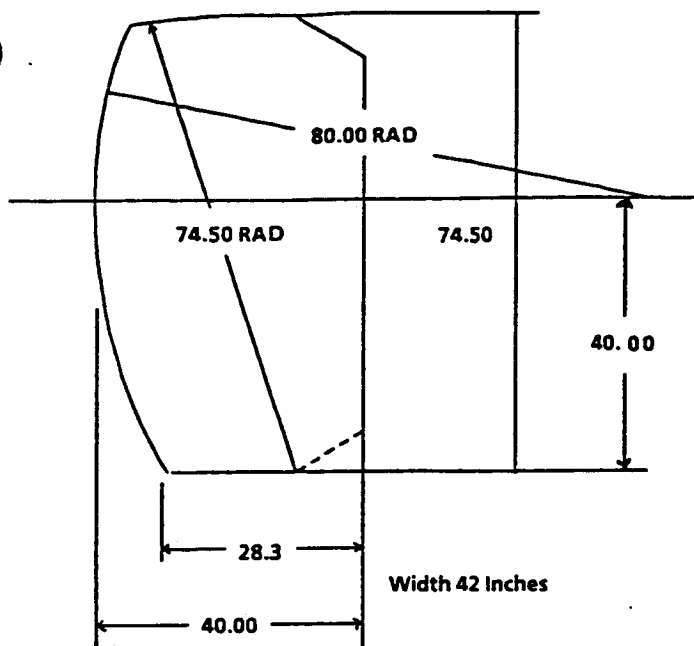


FUNCTIONAL UNIT SIZE

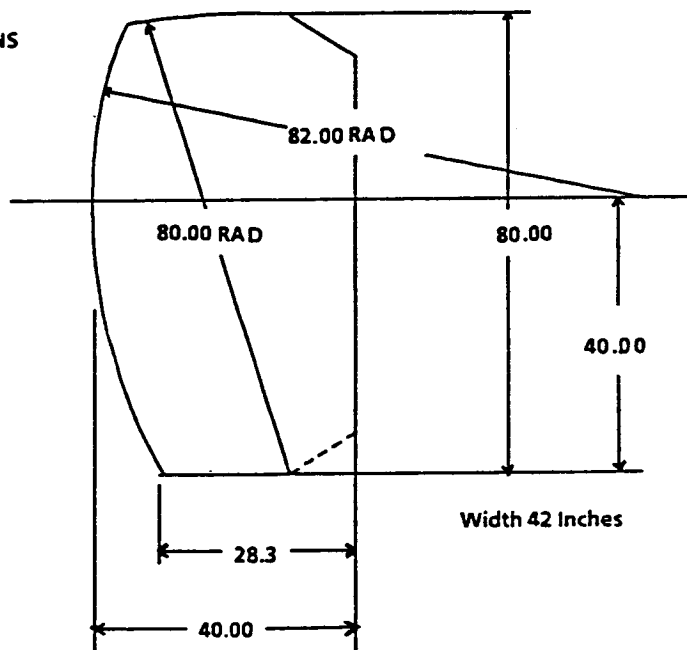


*BASELINE: RACKS REQUIRED TO BE COMMON BETWEEN MODULES

FIGURE 6.4.2.1-4 STANDARD RACK AND FUNCTIONAL UNIT ENVELOPE



STANDARD EQUIPMENT RACK ENVELOPE DIMENSIONS



FUNCTIONAL UNIT ENVELOPE

FIGURE 6.4.2.1-5 RACK AND FUNCTIONAL UNIT ENVELOPE

systems, logistics supply racks and some storage racks would benefit from this increased size.

After the overall architecture and the rack envelopes were defined, we began to identify the details of orienting and plumbing the racks, allowing wall and utility access, and accommodating special user or crew needs such as isolation, hazardous materials handling, special utilities, and lighting. Defining these details involved optimizing for several desirable attributes; lowest weight, least complexity, greatest flexibility, most room and growth and reconfigurability, easiest maintainability, and lowest IOC and recurring costs. The precise volume required for the utility trays continued to be defined as more information was forthcoming from the user groups and subsystem designers. One method of utility distribution optimization involved grouping payloads using "special" utilities such as high power/thermal or vacuum vent into zones within the module. Such zoning techniques save utility weight and reduce volume requirements.

The following pages describe the USL SDR Configuration. This design represents LaRC data base entries COMM 1201 AAX0907, and SAAX0401, and utilized the equipment and experiment requirement data base generated by the MMPF study (NAS8-36122).

6.4.2.2 USL Equipment Description

The USL will provide and maintain a shirt sleeve environment within the prescribed limits of pressure, atmospheric composition, temperature and humidity. The basic subsystems resources such as electrical power, thermal control, environmental control, communications, both audio and video, and data management through a multipurpose applications console will be provided. Any additional or supplemental

subsystems and laboratory equipment will be the responsibility of the outfitter.

6.4.2.2.1 Experiment Types

The MMPF and Mission Requirements Data Bases (MRDB) have identified the following experiment disciplines as being appropriate for inclusion in the USL:

- a. Biotechnology
- b. Crystals
- c. Glasses and ceramics
- d. Combustion
- e. Fluids and transport phenomena
- f. Metals/alloys
- g. Membranes/polymers
- h. Animal life science
- i. Plant life science
- j. Human life science

6.4.2.2.2 Experiments

The USL will accommodate the individual requirements of the following experiments defined by the data bases:

- a. Catalyst production
- b. Collagen processing
- c. Continuous flow electrophoresis
- d. Directional solidification
- e. Droplet burning
- f. Electroepitaxial crystal growth
- g. Electromagnetic containerless processing
- h. Eutectoid alloy solidification
- i. Free surface phenomena
- j. Membrane production

- k. Monodisperse latex spheres
- l. Protein crystal growth
- m. Solid surface burning
- n. Solidification of immiscible alloys
- o. Solution crystal growth
- p. Thermophysical properties
- q. Thin film crystal growth
- r. Transcrystallization in thermoplastics
- s. Undercooling/EM effects
- t. Vapor phase crystal growth
- u. Life sciences as defined by the red book

6.4.2.2.3 Experiment Facilities

Experiment facilities listed below are required to perform the experiments shown above.

- a. Combustion tunnel
- b. Directional solidification furnace
- c. Droplet combustion facility
- d. Electromagnetic containerless processing
- e. Electrophoresis facility
- f. Free surface apparatus
- g. Isothermal furnace
- h. Langmuir-Blodgett facility
- i. Latex reactor system
- j. Protein crystal growth facility
- k. Solution crystal growth facility
- l. Vapor crystal growth furnace
- m. Plant holding facility
- n. Animal holding facility

- o. 1.8m diameter centrifuge

6.4.2.2.4 Laboratory Support Equipment

The USL will provide the following laboratory support equipment for the IOC configuration:

Accelerometer unit, 3-axis recording
 Automated cutting/polishing unit
 Battery charger
 Cage cleaner
 Cameras and camera locker
 Centrifuges
 Chemical supply storage facility
 Cleaning equipment
 Digital multimeter
 Digital pressure transducer
 Digital recording oscilloscope
 Digital thermometers
 Electrical conductivity probe
 EM-shielded storage locker
 Environment monitoring system (dynamic, passive dosimeter, etc)
 Etching equipment
 Film locker
 Fluid handling tools
 Force measuring device
 Freezers (including cryo)
 Freeze drier
 General purpose hand tools (including soldering)
 Glovebox Incubator
 Kits (sample prep, dissecting, blood, etc)

Mass measuring device, (small and micro)

Metallographic microscope

Microtome

Microwave steam autoclave

Optical microscope and supplies

PH meter

Refrigerators

Stereo macroscope

UV/VIS/NIR spectrometer

UV sterilization oven

Video cameras and recorders

Workbench

X-ray diffraction unit

X-ray facility, general purpose

6.4.2.3 Equipment Integration

6.4.2.3.1 USL Layout Methodology

The rationale and methodology used in placing the equipment within the module are listed below:

- a. Equipment requiring high power (5 kW) are grouped in one area of the module.
- b. USL unique power subsystem equipment is located near the high power equipment area to reduce lengths of cables made from heavy gauge wire.
- c. Experiment facility equipment is grouped by discipline.
- d. General work area is located in the center of the module.

6.4.2.3.2 USL Equipment Layouts

The equipment layout for the 44 rack USL is shown in Figure 6.4.2.3.2-1.

6.4.3 Process Materials Management

The Process Material Management System (PMMS) is the integration of all of the materials handling systems which are required by the USL experiments for their operation. The PMMS encompasses the following subsystems; Process Fluids (delivery of fluids to the experiments for consumption), Hazardous Waste Removal (removes experiments waste, separates, and channels waste fluid to reclamation units), Vacuum Vent, (provides the experiments with an access to a vacuum), and Ultra Pure Water (reclaims and purifies water for experiment consumption). Descriptions of these subsystems along with their interfaces with the Common Module (core) and the customer are defined in the following subsections.

6.4.3.1 Process Fluids

6.4.3.1.1 Introduction

The purpose of this subsystem interface description is to define the USL process fluid distribution subsystem and its interfaces with the customer.

6.4.3.1.2 Scope

The following paragraphs, first, describe all requirements, assumptions and ground rules for the process fluid distribution subsystem. Secondly, the detailed subsystem configuration is summarized.

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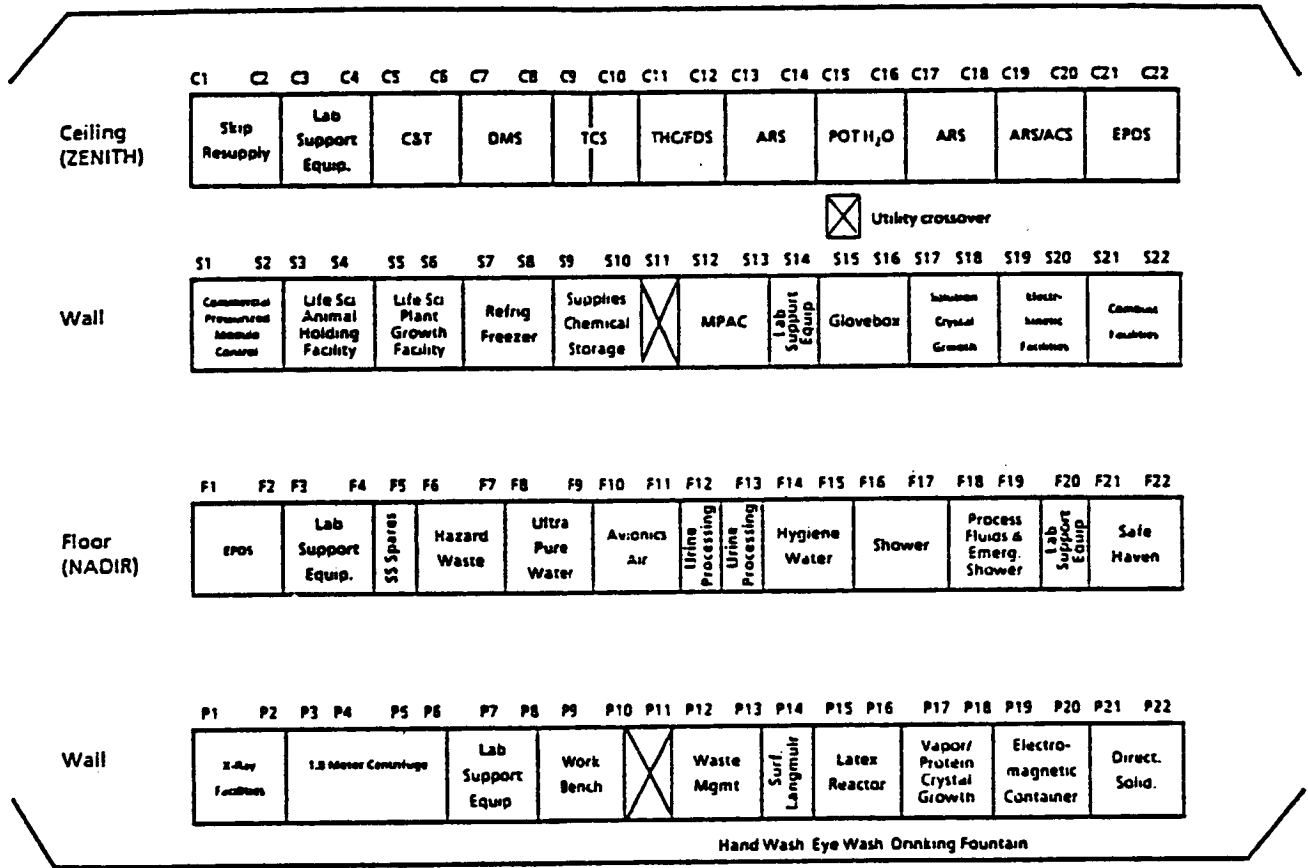


FIGURE 6.4.2.3.2-1 USL CONFIGURATION

6.4.3.1.3 Assumptions and Ground Rules

The following ground rules and assumptions have been utilized.

- a. Baseline Common Module length is 44.5 feet including end cones.
- b. The outfitted USL module will contain 44 equipment racks.
- c. 90 day resupply cycle.
- d. Equipment design and installation will readily support on-orbit reconfiguration or on-orbit initial installation.
- e. Process fluid feed throughs are located at one end of the module.
- f. External or internal storage of hazardous material shall be based on toxicity, corrosiveness, quantity and pressurization levels.

6.4.3.1.4 Requirements

6.4.3.1.4.1 Space Station General

- a. Determine fluid quantity in the storage system and during transfer operations.
- b. Acquire and transfer fluids independent of gravitational environment and specific orientation of any interfacing element.
- c. Minimize fluid losses due to venting, boil-off, leakage and during performance of subsystem maintenance.
- d. Utilize standardized fluid interface components to maximize commonality of fluid-handling hardware. Transfer interface hardware shall be

designed to preclude mating to the wrong fluid system.

- e. Preclude any unacceptable motions and/or moments between the fluid servicing facilities and the Space Station and/or interfacing element which may result from fluid storage, transfer dynamics and venting.
- f. Comply with EVA/TVA subsystems and capabilities when crew activity is utilized for fluid transfer and handling operations.
- g. Incorporate an operational monitoring capability with appropriate controls and status monitoring features that can function in either an automatic or semi-automatic mode during all fluid system operating phases.
- h. Incorporate design features that will provide inherent growth capability of the fluid storage and transfer system.
- i. As a design goal, the USL design shall be integrated with the Space Station design to minimize the number of unique fluids to be resupplied.
- j. Provide a unified approach to handling leaks, spills and associated cleanup.
- k. These facilities shall include resupply systems which are permanently space based and systems that are transported to required on-orbit locations.

1. Drains, vents and exhaust ports shall prevent fluids, gases and/or vapors, and flames from creating hazards to personnel, vehicles or equipment.

6.4.3.1.4.2 Laboratory General

The process fluid distribution subsystem shall consist of the necessary facilities to store, transfer, manage and service fluid consumables.

6.5.3.1.4.3 Laboratory Functional

Process fluids shall be made available to multiple users within the USL. Therefore, the distribution system should incorporate maximum flexibility to supply process fluids to all rack locations.

6.4.3.1.4.4 Laboratory Derived

Process fluids for the USL shall consist of gaseous hydrogen, gaseous argon, liquid nitrogen, gaseous nitrogen, water, gaseous oxygen and gaseous helium.

6.4.3.2 Configuration Description

6.4.3.2.1 Subsystem

The USL provided experiment consumable fluids shall consist of the following 1)gases; argon, carbon dioxide, helium, hydrogen, nitrogen and oxygen; 4)liquids; nitrogen and water. Hydrogen and carbon dioxide shall be stored in bottles as compressed gases until those bottles are attached to the user racks. All plumbed fluids except water, shall be supplied from externally mounted replaceable/rechargeable tanks. Water shall be stored internally, either in the nodes or a USL rack. Distributed systems for each of the six plumbed experiment process fluids are depicted in Figures 6.4.3.2.1-1 through 6.4.3.2.1-6.

Insulated tubing shall be used to pipe all fluids, except liquid nitrogen, which requires vacuum jacketed cryogenic tubing. After leaving the tank the fluids will first pass through a shutoff valve followed by a pressure regulator. This regulator will step down the pressure; the shutoff valve will provide an external cutoff point. Both components will be controlled automatically with manual override capability. The regulator will be followed by a check valve which will prevent evacuation of the internal lines should the external tank fail. Finally, the fluid piping enters the USL Laboratory through a pressure hull penetration.

Upon entering the USL Laboratory the fluid will pass through a second shutoff valve that provides an internal cutoff point. This valve shall be controlled automatically with manual override. The primary internal and external shutoff valves provide a dual capability to shut down flow. After the valve, each gas line shall contain a filter to remove particulates. Next, a regulator shall further step down the pressure. Following the regulator the gaseous fluid lines break into two line, one routed down each side of the laboratory, except for helium which shall be routed down only one side of the module. To permit branch isolation, shutoff valves shall be included in both distribution system branches. Equally spaced keyed quick disconnect outlets shall be available from each branch. Check valves, immediately upstream of the quick disconnects, shall prevent contamination of the fluid lines by users.

Liquid nitrogen shall be distributed in a similar manner to the gases described in the preceding paragraph. However, it shall not require a fluid filter nor the additional internal pressure regulator, and shall only

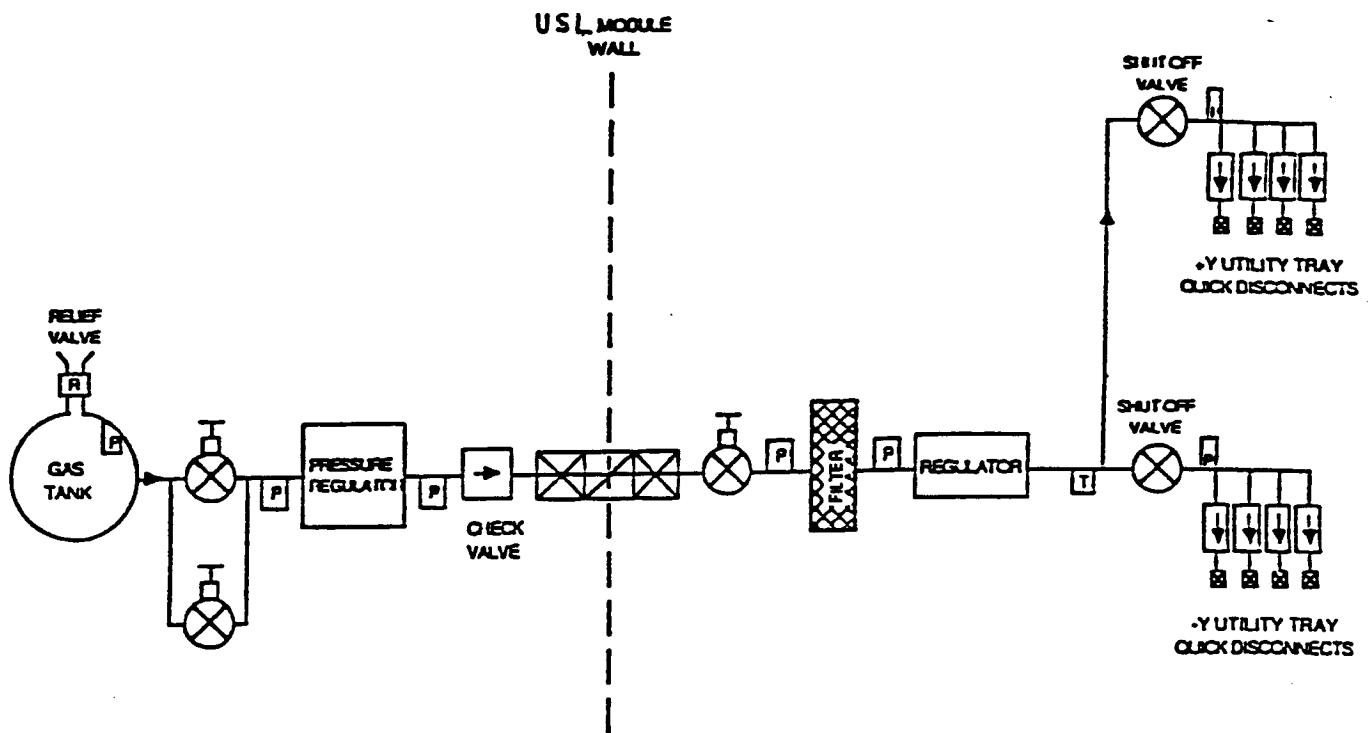


FIGURE 6.4.3.2.1-1 INERT PROCESS GAS DISTRIBUTION SYSTEM

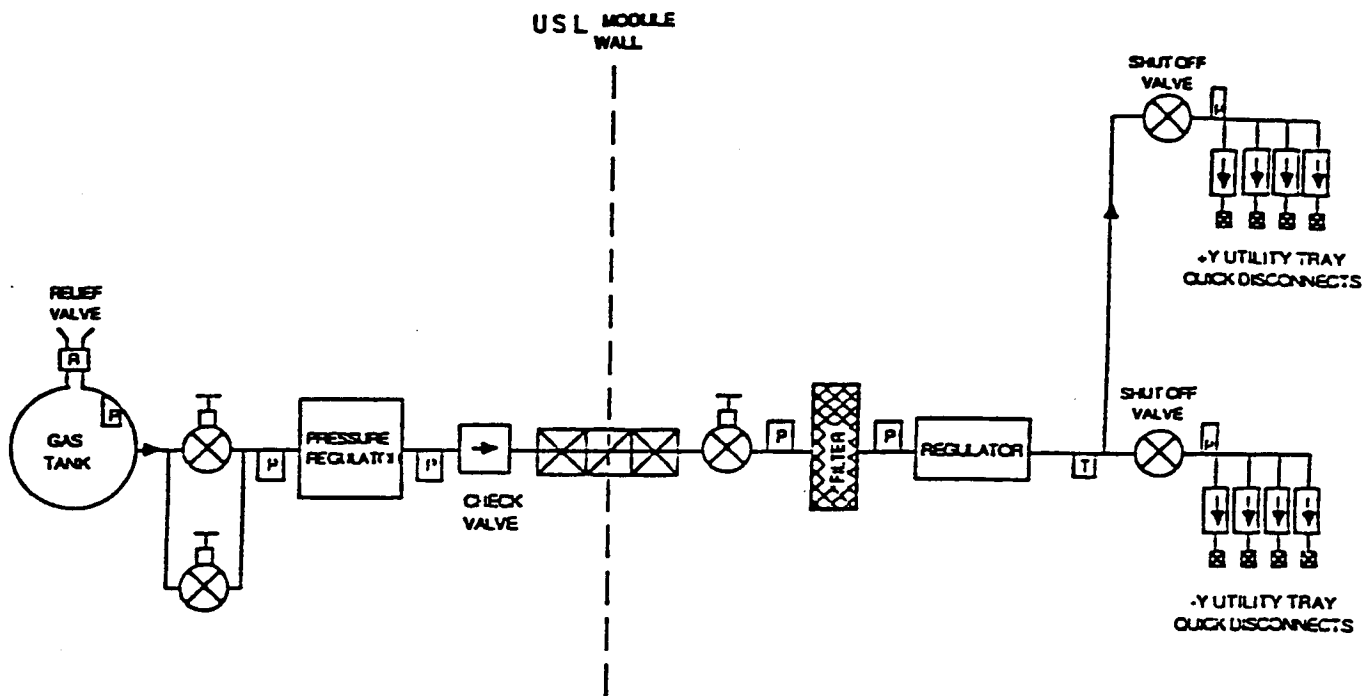


FIGURE 6.4.3.2.1-2 OXYGEN PROCESS GAS DISTRIBUTION SYSTEM

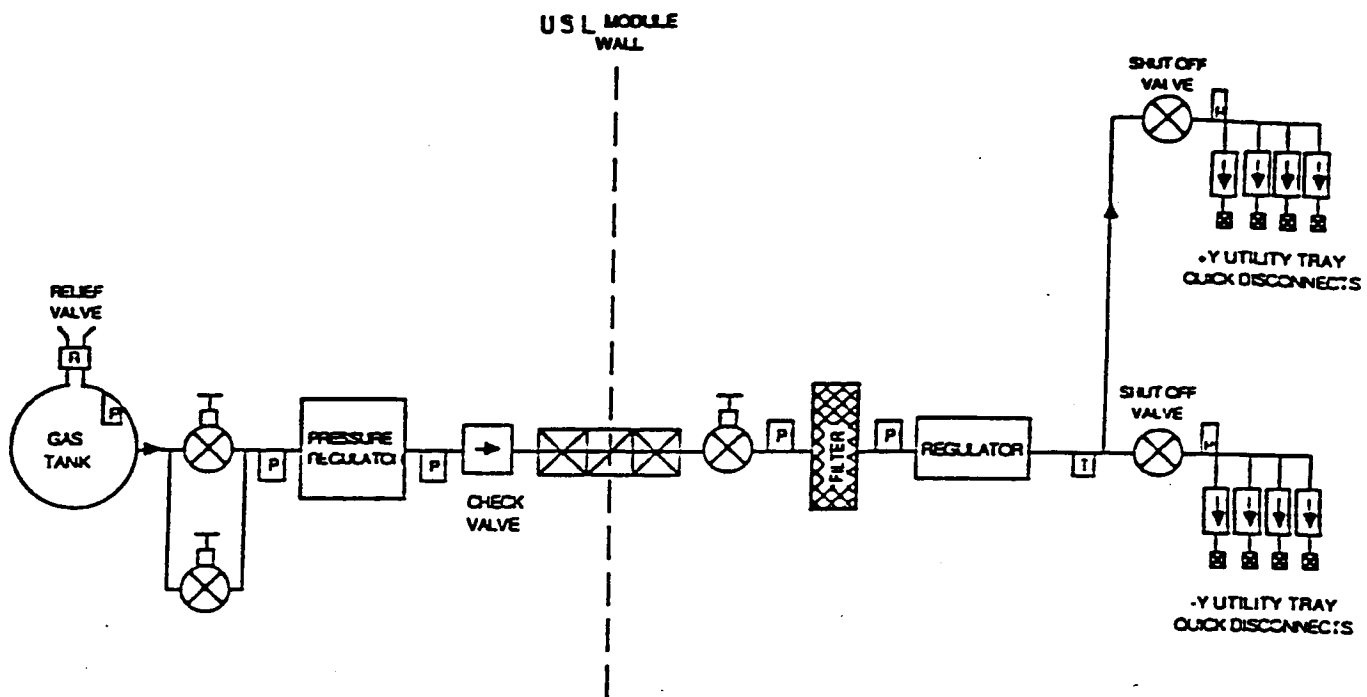


FIGURE 6.4.3.2.1-3 NITROGEN PROCESS GAS DISTRIBUTION SYSTEM

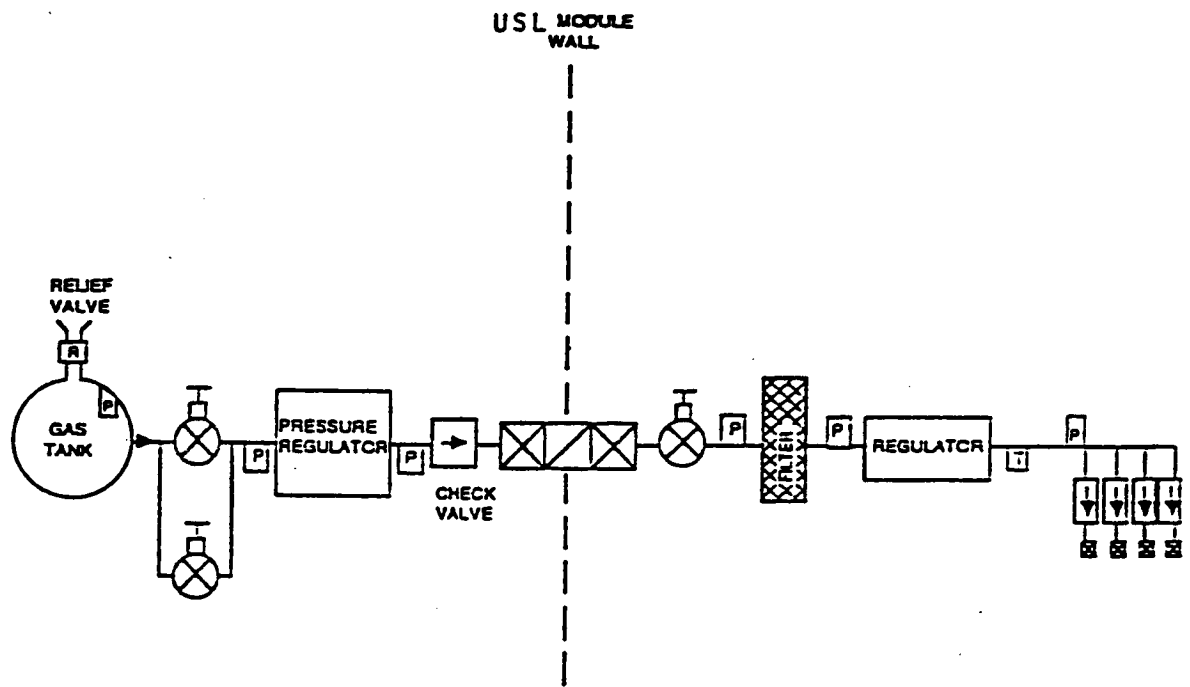


FIGURE 6.4.3.2.1-4 HELIUM PROCESS GAS DISTRIBUTION SYSTEM

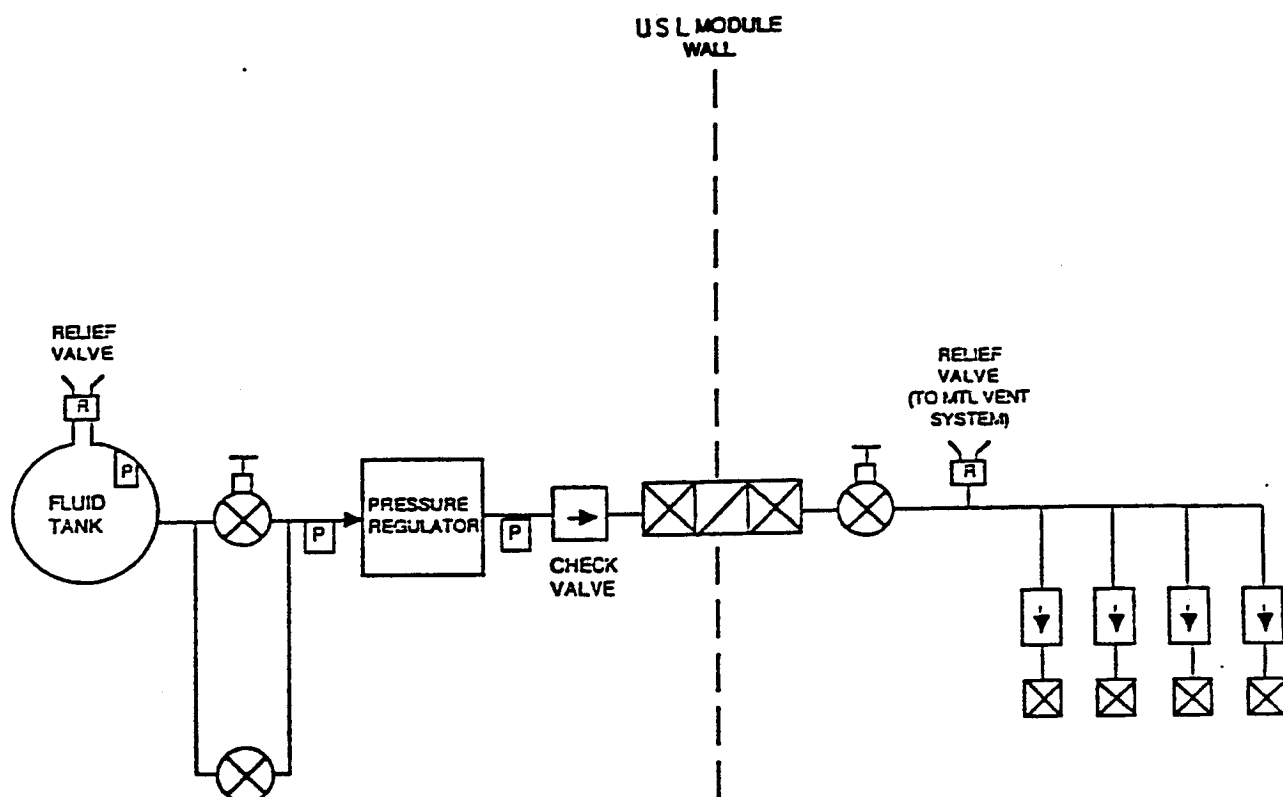


FIGURE 6.4.3.2.1-5 LIQUID NITROGEN PROCESS FLUID DISTRIBUTION SYSTEM

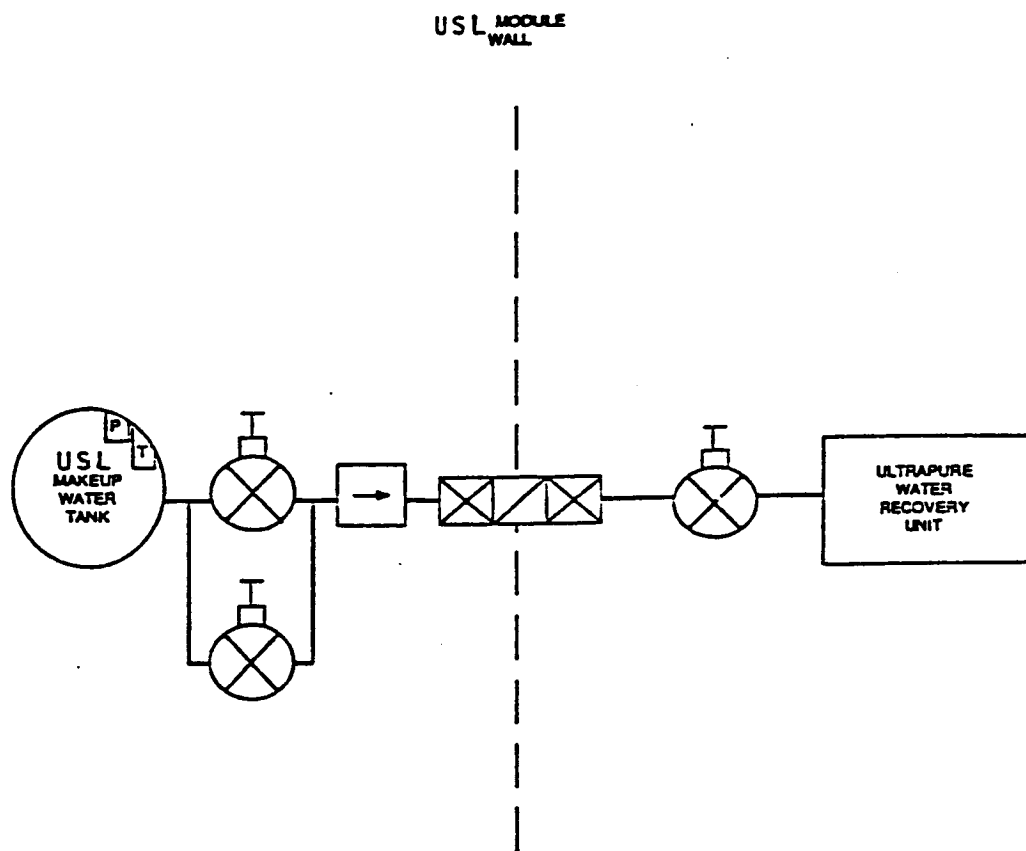


FIGURE 6.4.3.2.1-6 PROCESS WATER DISTRIBUTION SYSTEM

be distributed down one side of the laboratory module.

6.4.3.2.2 Components

6.4.3.2.2.1 Oxygen, Argon, Helium and Nitrogen Compressed Gas Tanks

The tanks shall be insulated, spherical, replaceable/rechargeable containers for external storage of compressed gasses.

They shall be designed to leak-and-not-burst if over-pressurized.

6.4.3.2.2.2 Liquid Nitrogen Tank

The tank shall be an insulated, spherical, cryogenic, replaceable/rechargeable container for external storage of liquid nitrogen. It shall be designed to leak-and-not-burst if over-pressurized.

6.4.3.2.2.3 Water Tank

The tank shall be an insulated, spherical, replaceable/rechargeable container for external storage of water. It shall contain an internal bladder which shall be kept pressurized by compressed gas and shall be designed to leak-and-not-burst if over-pressurized.

6.4.3.2.2.4 Relief Valves

The relief valves shall be preset mechanical valves designed to vent automatically when the fluid tank or lines are over-pressurized. Tank valves shall vent to space and the internal line relief valves shall vent to the Waste Management System.

6.4.3.2.2.5 External Shutoff Valves

These valves shall provide an external point for isolating the external storage tanks from their associated distribution

system. They shall be automatically controlled with a manual override capability.

6.4.3.2.2.6 External Pressure Regulator

These shall be high pressure regulators designed to step-down the pressure of their associated storage tank. They shall be automatically controlled by the USL.

6.4.3.2.2.7 High Pressure Transducers

These transducers shall be designed to measure the high pressure levels of the external storage tanks.

6.4.3.2.2.8 External Check Valves

These valves shall be spring loaded, installed externally and used to prevent evacuation of the internal distribution system should the external tank or lines depressurize.

6.4.3.2.2.9 Internal Low Pressure Regulator

These regulators shall reduce distribution feed line pressure to the internal operating levels. They shall be automatically controlled by the USL.

6.4.3.2.2.10 Internal Shutoff Valves

Internal shutoff valves shall provide fluid shutoff in the distribution systems. One shutoff valve shall be placed immediately following the USL hull penetration. This valve shall provide the capability to isolate the internal portion of the distribution system from the external portion. Additional valves shall be used to provide isolation capability for the various branches of multipath distribution systems.

6.4.3.2.2.11 Particulate Filter

These filters, with replaceable elements shall remove particulate matter from the process fluids.

6.4.3.2.2.12 Pressure Transducer

These transducer shall measure the pressure levels of the fluid distribution lines and external tanks.

6.4.3.2.2.13 Internal Check Valves

These valves shall be spring loaded and installed just upstream of the quick disconnects in the fluid distribution lines. They shall prevent experiment back pressures from contaminating the fluid distribution system lines.

6.4.3.2.2.14 Quick Disconnects

Quick connect/disconnect couplings, extending from the fluid distribution subsystem lines, shall provide an attach point for the user. Only the female half shall be provided by the USL. The male half shall be provided by the user.

6.4.3.2.2.15 Temperature Transducer

These transducers shall measure the temperature of the fluids in the distribution system.

6.4.3.2.2.16 Distribution Piping

Insulated piping will be used to transfer process fluids from the external storage tanks to the internal quick disconnects.

6.4.3.2.2.17 Cryogenic Tubing

Insulated metal piping shall be used to transfer liquid nitrogen from its external storage tank to the internal quick disconnects and the conversion unit. 6.4.3.2.3 Interface to Customer

The only interface with the customer for all fluids except for hydrogen shall be through the quick disconnects in the USL floor. The user shall be responsible for providing the mating half for the quick disconnects and the flex line to get the fluid from the disconnect to the rack. The interface for hydrogen shall consist of a hard mounted sealed connector attached directly to the user rack.

6.4.3.3 Mass Properties

Subsystem components and their masses are shown in Table 6.4.3.3-I.

6.4.3.3.1 Requirements Versus Design Accommodations Evaluation

The process fluid distribution system accommodates all defined requirements. First, the system is designed for growth and flexibility in meeting USL process fluid requirements. Second, a set of consumables which meets the requirements of a broad set of users is provided. Third, fluid quantities in the storage system are monitored and quantity data are provided to the USL data management system. Fourth, the resupply and fluid transfer concepts comply with Space Station EVA/IVA capabilities. Finally, all safety requirements for the system shall be met.

6.4.4 Emergency Shower

6.4.4.1 Introduction

Safety has established requirements for a USL provided system which will remove contaminants from a crew persons exterior in a quick and safe manner. As a result of these requirements a concept has evolved for an emergency full body shower.

TABLE 6.4.3.3-I PROCESS FLUID DISTRIBUTION SUBSYSTEM WEIGHTS (kg)

	QTY	UNIT MASS (kg)	TOTAL MASS (kg)	HEIGHT (m)	WIDTH (m)	DEPTH
CARBON DIOXIDE						
BOTTLE, GAS STORAGE	3	2.3	6.8	0.13	0.13	0.13
GASEOUS HELIUM FILTER	1	0.5	0.5	0.05	0.05	0.03
QUICK DISCONNECT	4	0.9	3.6	0.01	0.01	0.01
REGULATOR, PRESSURE	2	0.3	0.7	0.11	0.03	0.03
SENSOR, PRESSURE	6	0.1	0.4	0.03	0.03	0.05
TANK, STORAGE	1	25.9	25.9	0.48	0.48	0.48
TUBING	1	3.0	3.0	0.01	0.01	34.00
VALVE, CHECK	5	0.1	0.5	0.01	0.01	0.04
VALVE, RELIEF	1	0.2	0.2	0.02	0.02	0.10
VALVE, MANUAL						
OVERRIDE SH	3	0.3	0.8	0.07	0.11	0.04
FITTING, UNION TEE	5	0.1	0.5	0.03	0.06	0.02
FITTING, ELBOW	3	0.1	0.2	0.04	0.04	0.02
FITTING, UNION	14	0.0	0.3	0.02	0.02	0.03
FITTING, CONNECTOR	28	0.1	1.5	0.02	0.02	0.04
FITTING, BULKHEAD UNION	1	0.1	0.1	0.02	0.02	0.06
GASEOUS ARGON						
FILTER, FLUID	1	0.5	0.5	0.05	0.05	0.05
QUICK DISCONNECT	8	0.1	0.7	0.01	0.01	0.01
REGULATOR, PRESSURE	2	0.3	0.7	0.11	0.03	0.03
SENSOR, PRESSURE	7	0.1	0.5	0.03	0.03	0.05
TUBING	1	5.3	5.3	0.01	0.01	45.00
FITTING, UNION TEE	7	0.1	0.7	0.03	0.06	0.02
FITTING, ELBOW	4	0.1	0.3	0.04	0.04	0.02
FITTING, UNION	21	0.0	0.5	0.02	0.02	0.03
FITTING, CONNECTOR	42	0.1	2.3	0.02	0.02	0.04
VALVE, TWO WAY						
LATCHING S	2	0.2	0.4	0.05	0.08	0.03
VALVE, MANUAL						
OVERRIDE SH	3	0.3	0.8	0.07	0.11	0.04
VALVE, CHECK	9	0.1	0.9	0.01	0.01	0.04
FITTING, BULKHEAD UNION	1	0.1	0.1	0.02	0.02	0.06
VALVE, RELIEF	1	0.2	0.2	0.02	0.02	0.10
TANK, STORAGE	1	25.9	25.9	0.07	0.07	0.07
GASEOUS OXYGEN						
FILTER	1	0.5	0.5	0.05	0.05	0.03
QUICK DISCONNECT	8	0.9	7.2	0.01	0.01	0.01
SENSOR, PRESSURE	7	0.1	0.5	0.03	0.03	0.05
TANK, STORAGE	1	8.6	8.6	0.23	0.23	0.23
TUBING	1	5.3	5.3	0.01	0.01	45.00
VALVE, CHECK	9	0.1	0.9	0.01	0.01	0.04
VALVE, RELIEF	1	0.2	0.2	0.02	0.02	0.10
VALVE, TWO WAY	2	0.2	0.4	0.05	0.08	0.03
LATCHING 2						
FITTING, UNION TEE	7	0.1	0.7	0.03	0.06	0.02
FITTING, ELBOW	2	0.1	0.1	0.04	0.04	0.02
FITTING, UNION	21	0.0	0.5	0.02	0.02	0.03
FITTING, CONNECTOR	42	0.1	2.3	0.02	0.02	0.04

TABLE 6.4.3.3-I PROCESS FLUID DISTRIBUTION SUBSYSTEM WEIGHTS (kg)
(Cont'd)

VALVE, MANUAL OVERRIDE SH	3	0.3	0.8	0.07	0.11	0.04
REGULATOR, PRESSURE	2	0.3	0.7	0.11	0.03	0.03
FITTING, BULKHEAD UNION	1	0.1	0.1	0.02	0.02	0.06
GASEOUS HYDROGEN BOTTLE, GAS STORAGE	2	6.8	13.6	0.20	0.20	0.20
GASEOUS NITROGEN FILTER, FLUID	1	0.5	0.5	0.05	0.05	0.03
QUICK DISCONNECT	8	0.9	7.3	0.01	0.01	0.10
REGULATOR, PRESSURE	2	0.3	0.7	0.11	0.03	0.03
SENSOR, PRESSURE	7	0.1	0.5	0.03	0.03	0.05
TANK, STORAGE	1	34.4	34.4	0.88	0.88	0.88
TUBING	1	5.3	5.3	0.01	0.01	45.00
VALVE, CHECK	9	0.1	0.9	0.01	0.01	0.04
VALVE, RELIEF	1	0.2	0.2	0.02	0.02	0.10
VALVE, TWO WAY	2	0.2	0.4	0.05	0.08	0.03
LATCHING S						
FITTING, UNION TEE	7	0.1	0.7	0.03	0.06	0.02
FITTING, ELBOW	2	0.1	0.1	0.04	0.04	0.02
FITTING, UNION	21	0.0	0.5	0.02	0.02	0.03
FITTING, CONNECTOR	42	0.1	2.3	0.02	0.02	0.04
VALVE, MANUAL OVERRIDE SH	3	0.3	0.8	0.07	0.11	0.04
FITTING, BULKHEAD UNION	1	0.1	0.1	0.02	0.02	0.06
LIQUID NITROGEN REGULATOR, CRYOGENIC	1	1.0	1.0	0.14	0.04	0.03
PRESSURE SENSOR, CRYOGENIC	3	0.1	0.2	0.01	0.01	0.04
PRESSURE TANK, CRYOGENIC EXTERNAL	1	17.2	17.2	0.50	0.50	0.50
TUBING, CRYOGENIC	1	3.2	3.2	0.01	0.01	27.00
VALVE, CRYOGENIC CHECK	1	0.2	0.2	0.03	0.03	0.04
VALVE, CRYOGENIC RELIEF	2	0.4	0.7	0.04	0.04	0.10
VALVE, CRYOGENIC	4	1.0	3.8	0.11	0.08	0.04
MANUAL O						
FITTING, ELBOW	3	0.1	0.2	0.04	0.04	0.02
FITTING, UNION	8	0.0	0.2	0.02	0.02	0.03
FITTING, CONNECTOR	16	0.1	0.9	0.02	0.02	0.04
FITTING, BULKHEAD UNION	1	0.1	0.1	0.02	0.02	0.06
VACUUM JACKETING	1	1.0	1.0	0.01	0.01	7.00
SUBSYSTEM TOTAL			209.7			

6.4.4.2 Scope

The USL Emergency Shower defined shall require interfaces with several other USL subsystems and shall be centrally located in the laboratory in the area of most probable use.

6.4.4.3 Reference Documentation

The following documents were used in the preparation of this document.

- a. N/A "Microgravity and Materials Processing Facility (MMPF) Study Data Release, June 1986"
- b. SS-SRD-0001 "Space Station Program Definition and Requirements Document"
- c. SS-SPEC-0002 "Contract End Item Specification for the Space Station United States Laboratory Module"
- d. SS-IRD-0200 "Interface Requirements Document Customer to U.S. Laboratory for IOC Station"
- e. NASA "Technical Memorandum Life Sciences Space Station 89188 Planning Document: Ref. A Payload for the Life Sciences Research Facility"

6.4.4.4 Groundrules and Assumptions

The following list of groundrules and assumptions were used in the development of the data contained in this document:

- a. After IOC the resupply cycle will occur at 90 day intervals.
- b. Subsystem power shall be supplied and distributed by the USL.
- c. Subsystem cooling shall be provided as required by the USL.

- d. The subsystem's gas pressures and activation status shall be monitored by the Caution and Warning System.

6.4.4.5 Requirements

6.4.4.5.1 Laboratory General

An emergency shower shall be included in the USL outfitting.

6.4.4.5.2 Laboratory Functional

An USL Emergency Shower shall provide the means of a quick and safe removal of hazardous materials from a crew person's body in the event of a laboratory accident.

6.4.4.5.4 Laboratory Derived

The following are derived requirements .

- a. The shower shall be located to maximize crew access.
- b. The shower shall be operating in 5 seconds or less after initial activation.
- c. The shower shall be configured such that an injured crew member may be aided by another person.
- d. The shower shall be interfaced with the Caution and Warning System in order to monitor operational readiness/activation.
- e. The shower shall be capable of delivering a minimum of 6 liters of potable or standard wash water at any time.
- f. The shower shall be sized to contain water around the body of a 95 percent USAF male whose hip flexion

angle is approximately 90 degree (injured crew member).

- g. The shower shall be capable of totally flushing a human body in 180 seconds after operation begins.
- h. The shower facility shall be configured for reuse after each operation.

6.4.4.6 Configuration Description

6.4.4.6.1 Subsystem

These arrangements permit easy and quick access to the shower, removal of harmful contaminants, and access to the contaminated individual in the shower.

The shower bag is housed in its storage box until the door is opened, Figures 6.4.4.6.1-1 and 6.4.4.6.1-2. When activated by opening the door, the bag fills with air from the avionics system. A double, reinforced, overlapping slit in the side of the bag allows entry. Breathing air and water are activated when the breathing mask/eye wash is removed from the wall mount. Breathing air is supplied by the USL Avionics Air System and water is supplied by a three-liter storage tank. A vacuum port shall be available to clean up the shower and aid in its stowing. Figure 6.4.4.6.1-3 depicts the activation sequence for these concepts.

The shower enclosure is housed in the ceiling, Figure 6.4.4.6.1-4. The gas charge is released, deploying the enclosure when the hand-held shower sprayer is removed from its mount. At the same time avionics air is circulated in the enclosure, from the ceiling down. When the button on the hand held sprayer is pressed, rinse water is emitted and the vacuum inlets are connected to the waste removal system. The vacuum inlets in the sprayer shall also be

used for clean-up and aid in stowing the shower. Figure 6.4.4.6.1-5 depicts the activation sequence for this concept.

In all three concepts, when the emergency shower is initially activated the caution and warning system is also activated in order to alert other crew members of emergency shower deployment.

6.4.4.6.2 Components

Table 6.4.4.6.2-I is a listing of the components used in the USL Emergency Shower.

6.4.4.6.3 Interface to Common Module

The Common Module shall provide internal hard points for mounting the emergency shower storage container and supply lines.

6.4.4.6.4 Interface to Customer

None

6.4.4.6.5 Interface to Other Systems

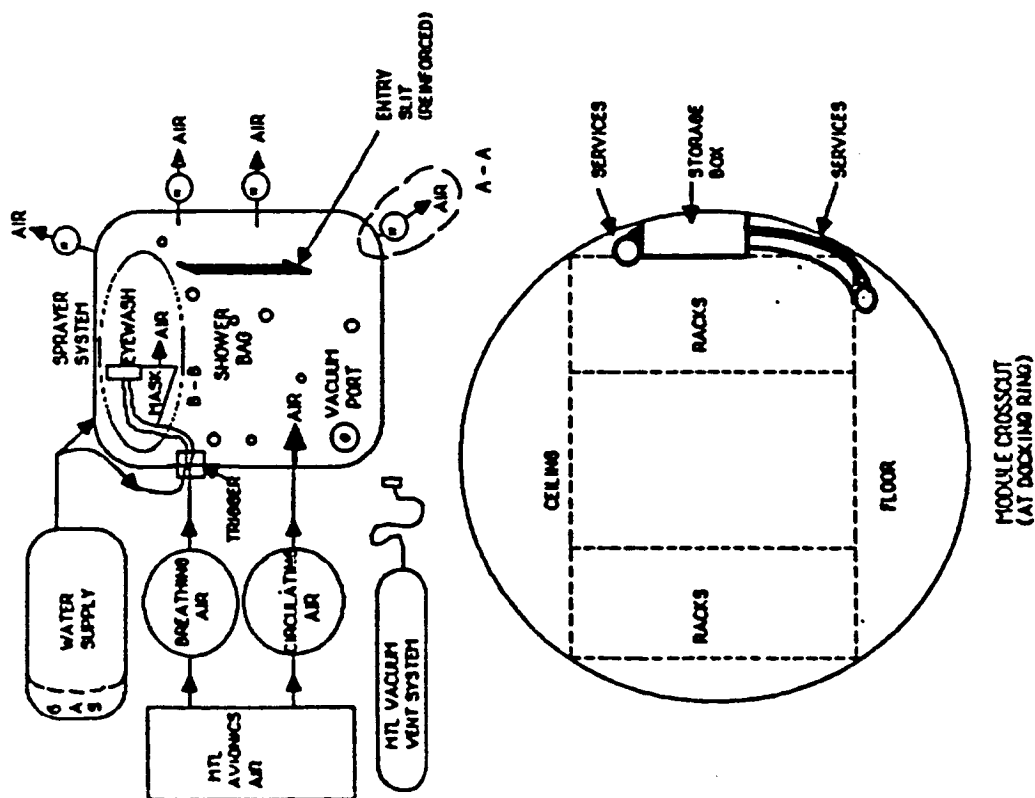
Listed below are the interface requirements to other systems required for the USL Emergency Shower:

- a. The USL shall provide interface connections from the Avionics Air System.
- b. The USL shall provide interface connections from the Waste Removal System.
- c. The caution and warning system shall monitor pressure and activation status of the USL Emergency Shower.
- d. The USL shall provide an interface with the USL Electrical System.

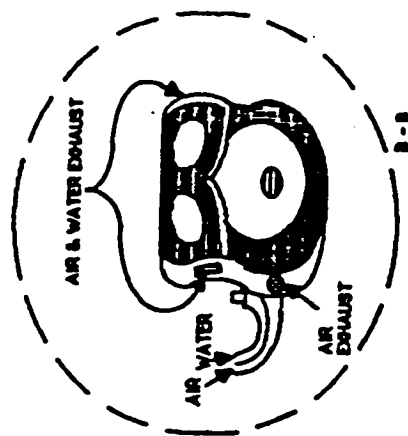
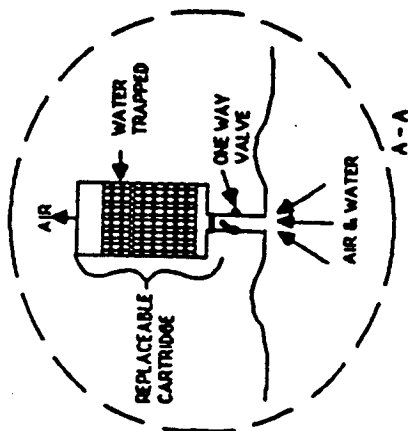
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GOALS:

- MAKE THE SHOWER AS AUTOMATIC AS POSSIBLE.
- MAKE IT COMPACT & STORABLE.
- MAKE IT REFURBISHABLE & REPACKABLE.
- MAKE IT SO A CREW MEMBER CAN ASSIST ANOTHER CREW MEMBER IF NEEDED.



- DESICCANT CARTRIDGES
- WATER SPRAYERS



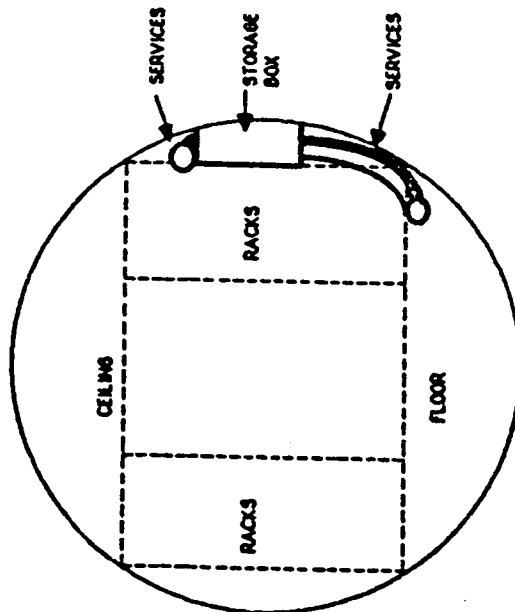
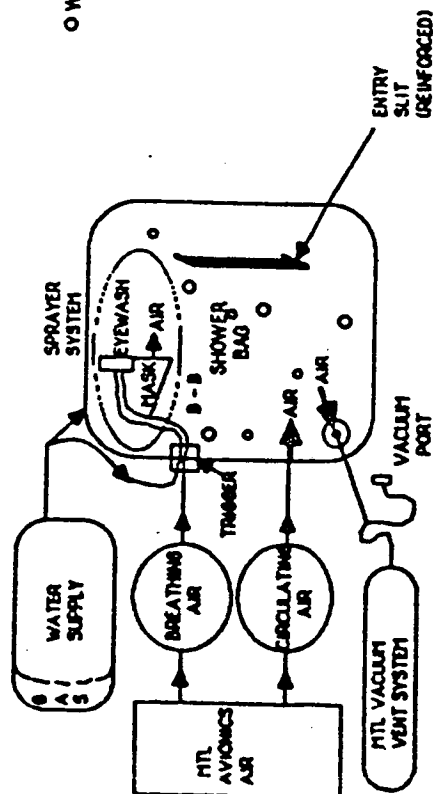
1. INFLATES IN - 8 SEC.
2. 3 LITERS OF WATER AVAILABLE (GAS DRIVEN)
3. CLEAN UP & REPACKAGING USING MTL VACUUM VENT SYSTEM
4. SHOWER BAG INFLATES AUTOMATICALLY WHEN WALL STORAGE BOX IS OPENED
5. BREATHING AIR & SHOWER WATER IS ACTIVATED WHEN MASK IS REMOVED FROM STORAGE PLACE
6. ENTRY SLIT IS A REINFORCED OVERLAPPING JOINT IN THE WALL OF THE BAG WHICH WILL SPRING CLOSED
7. EYE WASH ON MASK IS OPERATED BY BUTTON ON MASK
8. APPROX. STORAGE SIZE (36 X 18 X 6) (CONTOURED)
9. CAUTION & WARNING SYSTEM ACTIVATES AN ALARM WHEN STORAGE BOX IS OPENED

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FIGURE 6.4.4.6.1-1 USL EMERGENCY SHOWER CONCEPT 1

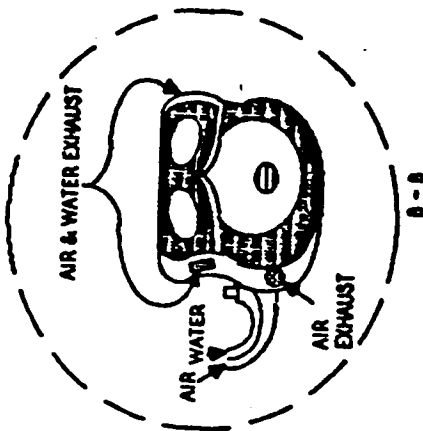
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- MAKE THE SHOWER AS AUTOMATIC AS POSSIBLE.
- MAKE IT COMPACT & STORABLE.
- MAKE IT REFURBISHABLE & REPACKAGEABLE.
- MAKE IT SO A CREW MEMBER CAN ASSIST ANOTHER CREW MEMBER IF NEEDED.



MODULE CROSSCUT
(AT DECKHEAD RING)

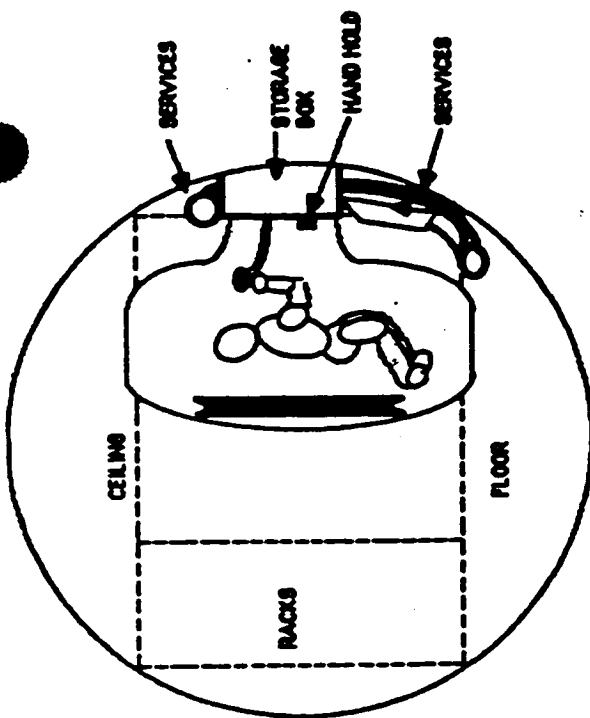
1. INFLATES IN - 0 SEC.
- 2-3 LITERS OF WATER AVAILABLE (GAS DRIVEN)
3. CLEAN UP & REPACKAGING USING MITL VACUUM VENT SYSTEM
4. SHOWER BAG INFLATES AUTOMATICALLY WHEN WALL STORAGE BOX IS OPENED
5. BREATHING AIR & SHOWER WATER IS ACTIVATED WHEN MASK IS REMOVED FROM STORAGE PLACE
6. ENTRY SLIT IS A REINFORCED OVERLAPPING JOINT IN THE WALL OF THE BAG WHICH WILL SPRING CLOSED
7. EYE WASH ON MASK IS OPERATED BY BUTTON ON MASK
8. APPROX. STORAGE SIZE (36 X 18 X 8) (CONTOURED)
9. CAUTION & WARNING SYSTEM ACTIVATES AN ALARM WHEN STORAGE BOX IS OPENED
10. BAG INFLATION AIR IS CIRCULATED THROUGH THE SHOWER AND THEN REMOVED THROUGH THE VACUUM VENT TAKING WASH WATER WITH IT



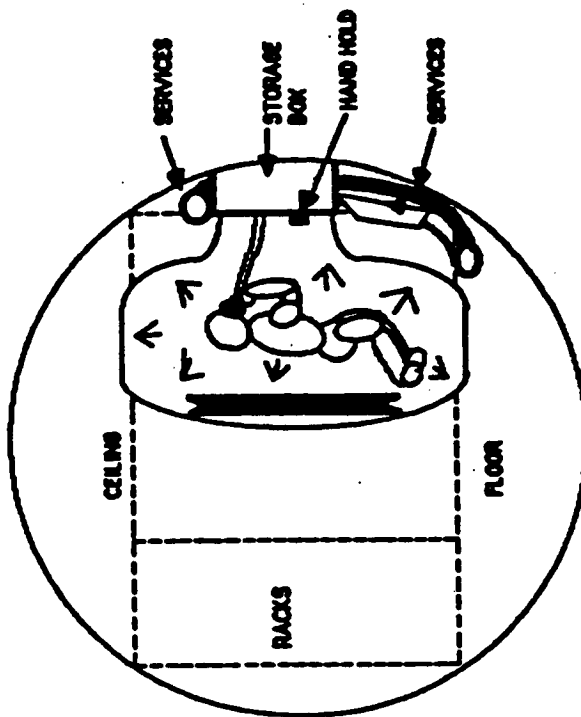
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FIGURE 6.4.4.6.1-2 USL EMERGENCY SHOWER CONCEPT 2

FIGURE 6.4.4.6.1-2 USL EMERGENCY SHOWER CONCEPT 2

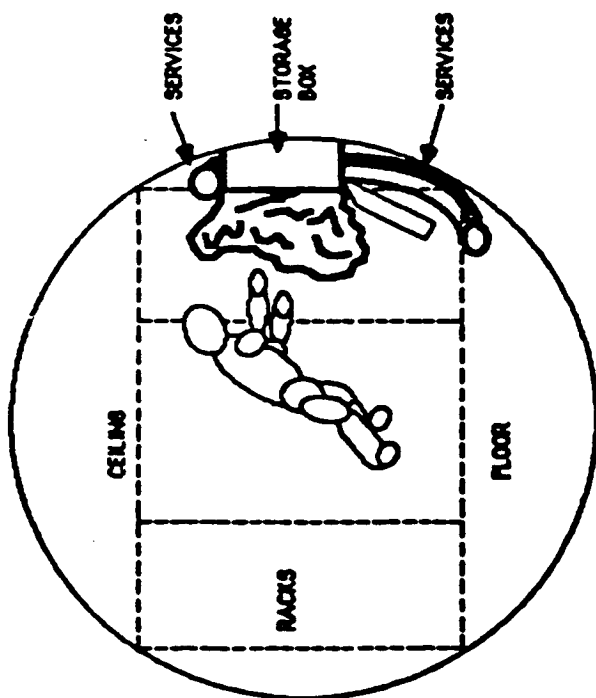


MODULE CROSSCUT
(AT DOCKING RING)
STEP 3

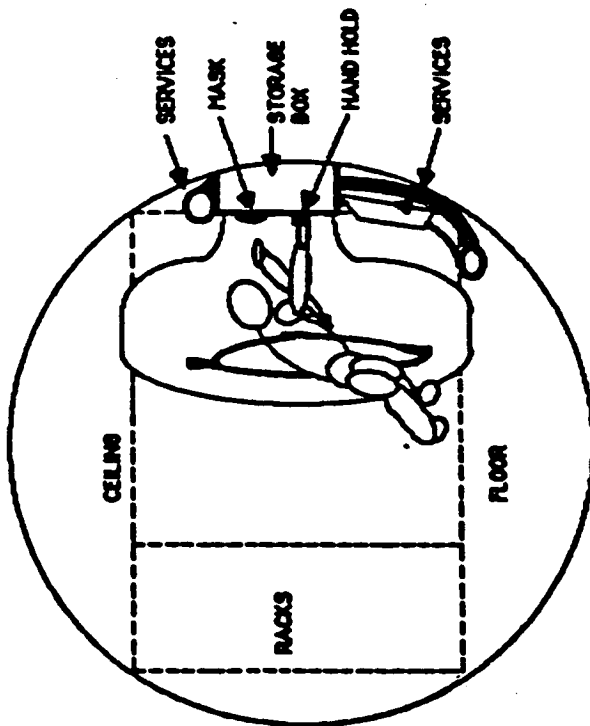


MODULE CROSSCUT
(AT DOCKING RING)
TOTAL ACTIVATION

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MODULE CROSSCUT
(AT DOCKING RING)
STEP 1



MODULE CROSSCUT
(AT DOCKING RING)
STEP 2

FIGURE 6.4.4.6.1-3 EMERGENCY SHOWER CONCEPT 1 & 2 ACTIVATION
SCENARIO

FIGURE 6.4.4.6.1-3 EMERGENCY SHOWER CONCEPT 1 & 2 ACTIVATION
SCENARIO

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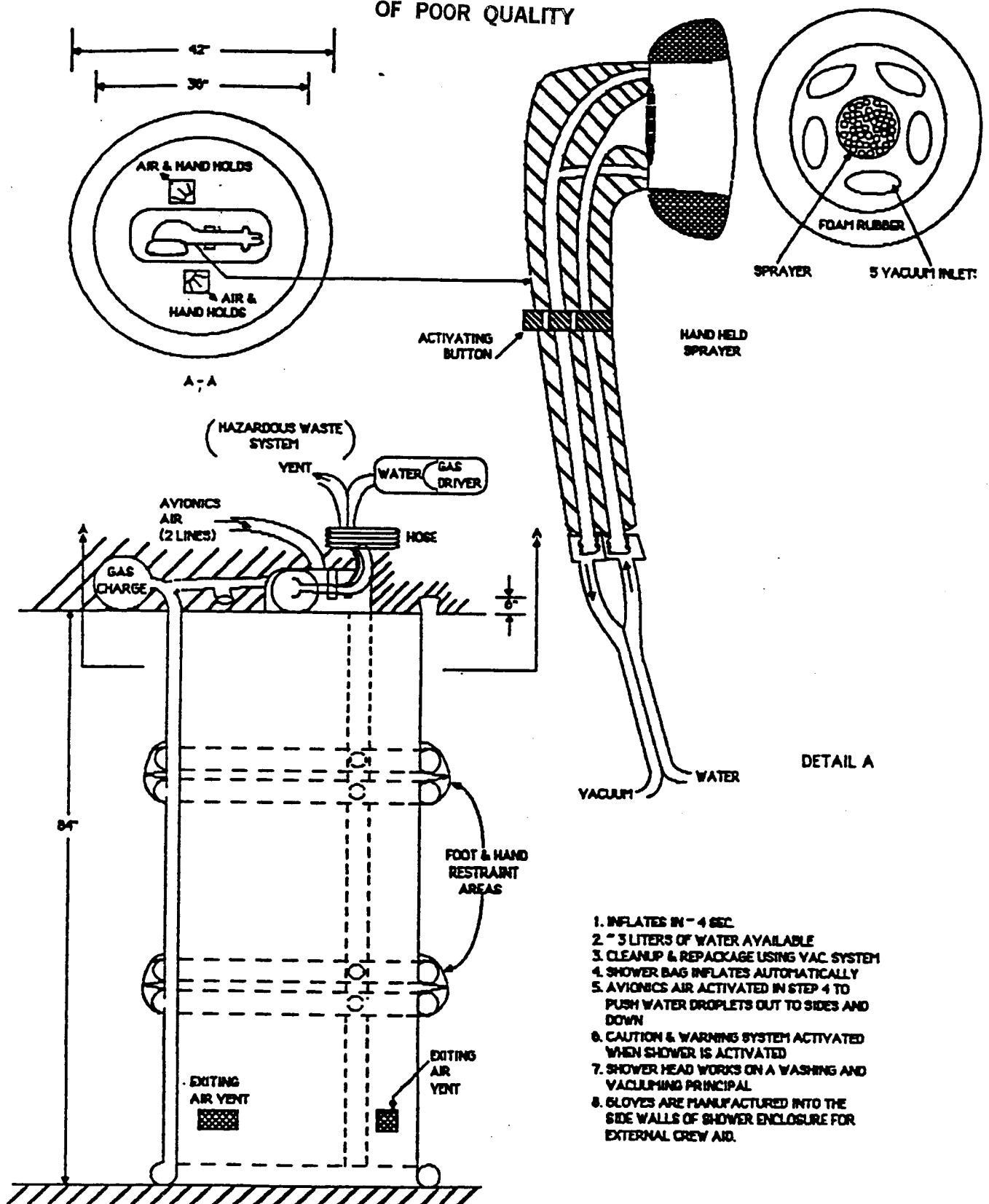


FIGURE 6.4.4.6.1-4 USL EMERGENCY SHOWER CONCEPT 3

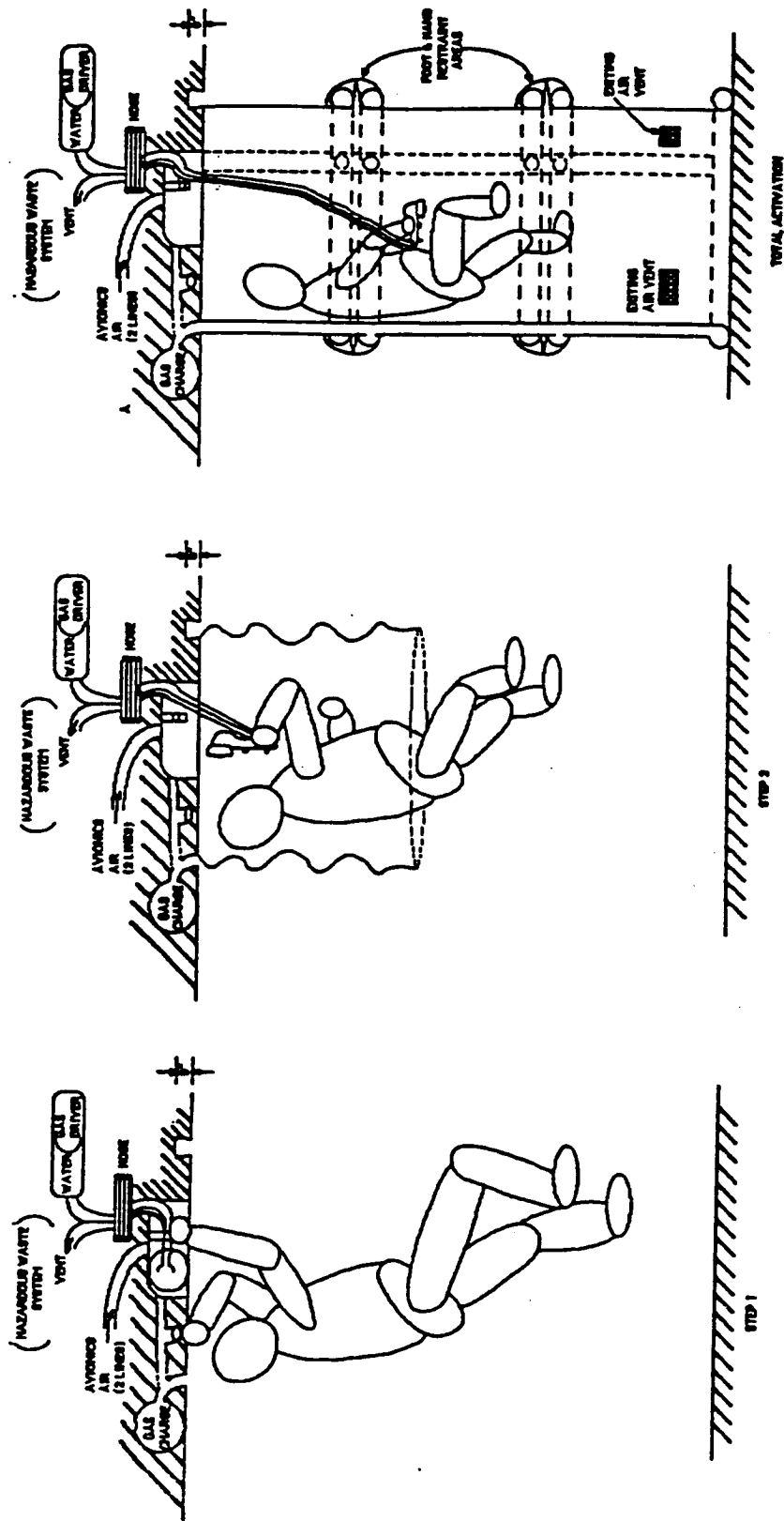


FIGURE 6.4.4.6.1-5 USL EMERGENCY SHOWER CONCEPT 3 ACTIVATION SCENARIO

TABLE 6.4.4.6.2-I EMERGENCY SHOWER COMPONENTS

Component	Description
Tubing/Fittings	Stainless steel (3/8 in.)
Pressure Sensor	Provides ability to monitor pressure
Water Filter	Removes particulate matter from water
Quick Disconnect	Interface valve w/thumb wheel shut offs in each half to prevent leaking when connection is broken (3/8 in.)
Shower Enclosure	Flight qualified plastic tube w/air pockets built in for inflation
Water Tank W/Bladder	Vessel w/separating wall for retaining water under pressure (4 liter)
Ducting	Aluminum walled tube, provides air flow (3 in.)
Butterfly Valve	Isolates air flow (3 in.)
Trigger Valve	Automatic opening valve when activated
Manual and Electric Valve	Isolates system flow (3/8 in.)
Gas Charge Tank	Vessel for retaining nitrogen under pressure (1 liter)
Hand Held Sprayer	Dispenses water and provides mild vacuum removal of water (Rinse-Vacuum Concept)

6.4.4.6.6 Functional Block Diagram

The general concepts of the USL Emergency Shower are shown in Figures 6.4.4.6.1-3 and 6.4.4.6.1-5.

6.4.4.6.7 Mass Properties

System components and their masses are shown in Tables 6.4.4.6.7-I and 6.4.4.6.7-II.

6.4.4.6.8 Requirements Versus Design Accommodations Evaluation

No restrictions identified.

6.4.5 Laboratory Support Equipment

As a part of the resource provisioning of the USL, certain items of support equipment will be manifested according to the needs of the mission payload set. This equipment will be selected from the list of requirements provided by the USL and

customers from their functional analyses. Where items of equipment are of such a general nature and in frequent demand, they will be installed as part of the USL baseline configuration and although subject to change-out as circumstances dictate, will remain a permanent part of the USL. An example is the glovebox.

Other items that are in less demand but required by and shared by a number of users, will be provisioned and changed out according to the mission schedule. Where support equipment is of a specific nature and peculiar to single customers, it will be provided by that customer and installed to support his immediate needs.

6.4.5.1 Equipment Sources

Where a decision is required to determine the provisioning responsibility, costing, pricing, etc., for a particular piece of equipment, a method for determining these is shown in Figure 6.4.5.1-1.

TABLE 6.4.4.6.7-I EMERGENCY SHOWER MASS PROPERTY - CONCEPT 1&2

EMERGENCY SHOWER SUBSYSTEM

ITEM	HEIGHT	WIDTH	DEPTH	MASS (KG)
QUICK DISCONNECTS	0.07	0.07	0.16	1.0
SENSOR, PRESSURE	0.04	0.04	0.11	0.5
FILTER, POTABLE WATER	0.2	0.55	0.55	18.1
SHOWER BAG	1.8	0.9	0.9	4.9
STRUCTURE				22.6
TANK, WATER W/BLADDER	1.0	1.0	1.0	6.2
TUBING/FITTINGS	0.01	0.01		2.2
TUBING/FITTINGS AIR	0.01	0.01		1.0
DUCTING	0.06	0.06		4.5
VACUUM ATTACHMENT	0.03	0.03	0.02	2.5
VALVE, BUTTERFLY	0.15	0.08	0.09	1.1
VALVE, TRIGGER	0.07	0.05	0.06	6.1
VALVE, TWO WAY SHUT OFF	0.06	0.02	0.04	3.2
AIR MASK/EYE WASH	0.21	0.13	0.09	1.5
CONTAINER, STORAGE	0.91	0.46	0.2	34.0
DESICCANT CARTRIDGES	0.1	0.03	0.03	7.6
EMERGENCY WASH SHOWER SUBSYSTEM				119.3

TABLE 6.4.4.6.7-II EMERGENCY SHOWER MASS PROPERTY - CONCEPT 3

EMERGENCY SHOWER SUBSYSTEM

ITEM	HEIGHT	WIDTH	DEPTH	MASS (KG)
QUICK DISCONNECTS	0.07	0.07	0.16	1.8
SENSOR, PRESSURE	0.04	0.04	0.11	0.5
FILTER, POTABLE WATER	0.2	0.55	0.55	18.1
SHOWER ENCLOSURE	2.13	1.07	1.07	3.9
STRUCTURE				11.3
TANK, WATER W/BLADDER	1.0	1.0	1.0	6.2
TUBING/FITTINGS	0.01	0.01		2.2
TUBING/FITTINGS AIR	0.01	0.01		1.8
DUCTING	0.06	0.06		4.5
VALVE, BUTTERFLY	0.15	0.08	0.09	1.1
VALVE, TRIGGER	0.07	0.05	0.06	6.1
VALVE, TWO WAY SHUT OFF	0.06	0.02	0.04	3.2
HAND HELD SPRAYER	0.3	0.15	0.12	0.9
TANK, GAS CHARGE	0.02	0.1	0.1	3.9
	0.1	0.03	0.03	7.6
EMERGENCY WASH SHOWER SUBSYSTEM				65.5

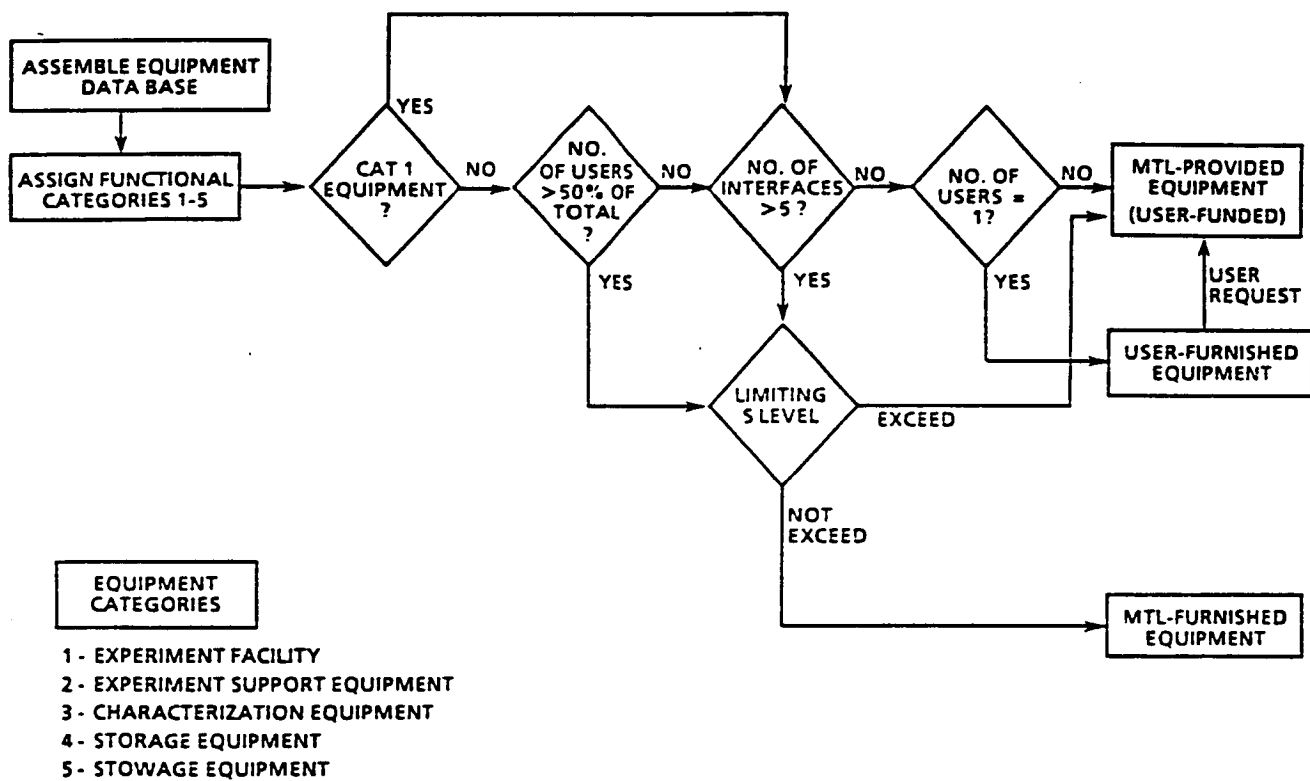


FIGURE 6.4.5.1-1 EQUIPMENT SOURCE SELECTION

6.5 INTRODUCTION

The Logistics Elements consist of four types of carriers to transport equipment and fluids to the Space Station. They are a common module derived pressurized module, an unpressurized cargo pallet, propellant carrier and an unpressurized Fluids Carrier. The pressurized module is designed to accommodate resupply and return of consumables and user hardware and to provide ready on-orbit access without Extravehicular Activity (EVA). The pressurized module will maintain a habitable environment for crew activities while providing a benign storage facility for user equipment. The Fluids Carrier is designed to accommodate Space Station ECLS and other user fluids to the extent of their compatibility. The propellant carrier will provide a resupply capability for all on station propellants. An unpressurized cargo pallet provides the capability to transport both fluids and dry cargo which will be utilized external to the modules.

The pressurized Logistics Module (LM) will be capable of docking at two center node earth side ports of the Space Station (SS). Space Station resources will be provided to the Pressurized Logistics Module via this interface, which will be tailored to provide specific logistics module interface capability. Other LM/SS interfaces include the Mobile Service Center (MSC) for handling and transfer, a docking area for the propellant carrier, an interface for propellant transfer, a docking area for unpressurized cargo pallet, docking area for the fluids carrier and an interface for fluid transfer.

6.5.1 Requirements

System Requirements for the Logistics Elements are contained in SS-SRD-0001. Logistics Elements to cargo interface requirements are contained in SS-IRD-300,

Logistics Elements to Space Station Interface requirements in SS-IRD-301, and Logistics Elements to NSTS Interface Requirements in SS-IRD-302. The major design requirements are summarized in the following paragraphs for reference only.

6.5.1.1 General Requirements

The integrated logistics system shall support all program phases for both on-orbit and ground operations and shall provide the following:

- a. The ability to transport cargo which requires a pressurized environment.
- b. The ability to transport cargo in an unpressurized environment.
- c. The ability to transport fluids.
- d. The ability to transport propellants.
- e. Provisions for the supply and control of electrical power, thermal control, information and data management and communications services to specified cargos.
- f. Inventory Management System for manifesting, ORU life cycle analysis, and C.G. calculations.
- g. Supply support of unmanned spacecraft (platforms).

6.5.1.2 System Design Requirements

The logistics system shall meet the following design requirements:

- a. Elements shall have the ability to remain operational for the minimum of 10 years or 40 flights through periodic inspection, maintenance, refurbishment.

bishment and/or replacement of components.

- b. Elements gross weight and overall dimensions will not violate shuttle and payload bay constraints.
- c. Provide meteoroid/debris protection at a 95 percent probability of nothaving a penetration for 10 years.
- d. Provide docking/berthing capability to the Space Station Nodes.
- e. Impose structural ultimate factors of safety for structural design analysis.
 - (1) Factor of safety of 2.0 for pressure loading.
 - (2) Factor of safety 1.5 for mechanical and thermal loading.

6.5.1.3 Pressurized Module

The Pressurized Module shall be a modified common module and shall meet the following requirements:

- a. Launch configuration of the pressurized module shall fit within constrained volume of orbiter bay.
- b. Provide trunion and keel fittings for transport in the orbiter payload bay.
- c. Provide internal volume which is optimized for utilization of STS lift capability.
- d. Primary structure shall resist damage from external sources.
- e. Provide one axial port.
- f. Provide two grapple fixtures.

- g. Be compatible with Space Station Interconnects.
- h. Provide flexible outfitting.
- i. Utilize standard interfaces between cylinder and end domes and between primary and secondary structure.
- j. Utilize self extinguishing interior walls and secondary structure.
- k. Secondary structure shall resist damage from internal forces.
- l. Provide one hatch capable of operation from either side.
- m. Provide strength and life integrity to sustain a manned shirt sleeve-environment of 14.7 psia in the pressurized element.
- n. Provide adequate internal attachment structure for pressurized element outfitting.
- o. Provide an opening to accommodate pass through of a standard rock in any of three axle. This opening shall be sealed with a closure which is removable for ground processing.

6.5.1.4 Unpressurized Cargo Pallet

The unpressurized cargo pallet shall utilize common module structure to the maximum extent consistent with good design. In addition, it shall meet the following requirements:

- a. Provide one grapple fitting.
- b. Provide internal attachment structure for outfitting.

6.5.1.5 Propellant Carrier

The propellant carrier shall be capable of transporting and storing the platform propellants and shall meet the following requirements:

- a. Provide trunion and keel fittings for transport in the STS and for attachment to the Space Station tower structure.
- b. Provide one grapple fitting.
- c. Provide plumbing with quick disconnects for servicing tanks and for transfer of propellants on station.
- d. Provide storage for pressurant gas for propellant transfer.

6.5.1.6 Unpressurized Fluids Carrier

The unpressurized fluids carrier shall provide the following:

- a. It will provide compartment to support ECLSS pressurizing tanks.
- b. It will provide tank support hardware.
- c. It will provide support brackets for plumbing.

6.5.1.7 Subsystems

All Logistics Element subsystems shall be common module systems to the maximum extent consistent with good design. The Logistics Elements subsystems shall meet the following requirements.

6.5.1.7.1 Environmental Control and Life Support System (ECLSS)

The ECLSS shall provide a shirt sleeve environment in the Pressurized Module suitable for occupancy by a two-man crew. It

shall interface with the Space Station ECLSS as specified in the Logistics Module to Space Station Interface Requirements Document. Specific performance parameters are given in the SS-SPEC-0003 Logistics Elements Contract End Item Specification.

A refrigerator/freezer will be provided for storage of food, user equipment and specimens.

6.5.1.7.2 Thermal Control System

Thermal control shall be provided to maintain structures, subsystems, components and customer payloads within the required temperature. Both active and passive systems shall be provided in the pressurized module. The active systems shall use a water loop with cold plates and/or heat exchangers to provide cooling to selected equipment. Passive thermal protection shall be provided to minimize temperature changes during unpowered periods while the pressurized module is detached from the station or orbiter. Thermal control of the unpressurized cargo carrier will be provided by Multi-layer Insulation (MLI) only with no active systems. The active system in the pressurized module shall interface with the Space Station Thermal Control System as specified in SS-IRD-301 and to the NSTS per SS-IRD-302.

6.5.1.7.3 Electrical Power System

The pressurized module electrical power system shall be capable of receiving and distributing 20 KHz power to selected rack locations. In addition, the system shall be capable of converting 28 VDC received from the orbiter or from onboard batteries to 20 KHz AC for distribution within the module. The fluids carrier and the propellant carrier shall be capable of receiving 20 KHz AC or 28 VDC for distribution to status indication systems and to propellant

heaters. The unpressurized cargo pallet will not require electrical power. A single point ground system shall be provided on all powered elements. Detailed system requirements are included in SS-SPEC-0003.

6.5.1.7.4 Communications

The pressurized module communications system shall support the transmission, reception, distribution, signal processing, and controlling of audio, commands, and video. Multiple duplex voice channels are required between the pressurized module and ground facilities. The module shall have internal wireless voice communications. Video monitoring of crew operations within the module will be provided. The Communications design shall provide the capability to record, process, amplify, mix, recognize, synthesize, switch and distribute voice and/or audio to/from internal locations.

6.5.1.7.5 Data Management System (DMS)

The pressurized module DMS shall provide Logistics System status information to the Space Station through the Multipurpose Applications Console. Systems to be monitored include:

- a. Inventory Management System
- b. ECLSS
- c. TCS
- d. Power
- e. Customer Payload Sensors

The DMS shall also provide status information to the STS during launch operations. The system shall use a user-friendly, general-purpose programming language with the capability to interface between man and machine for

communications, display generation, monitoring, checkout, and control. Capability shall also be provided for automatic ground checkout.

6.5.1.8 Cargo

The 90 day resupply cargo requirements are given in Figures 6.5.1.8-1 through 6.5.1.8-9.

6.5.1.9 Interfaces

Requirements for Interfaces of the Logistics Elements to other Space Station Program Elements are given in the following documents:

- a. SS-IRD-300, Logistics Elements to Cargo
- b. SS-IRD-301, Logistics Elements to Space Station
- c. SS-IRD-302, Logistics Elements to NSTS

6.5.1.10 Reliability

Reliability programmatic requirements shall be as specified in Space Station Program (SSP) (J8400001), "Product Assurance Requirements for the Space Station Program." Reliability design requirements for the logistics module are as follows.

6.5.1.10.1 Failure Tolerance

Safety critical and mission critical subsystems are those whose function, if lost, would produce a condition endangering on-board personnel or prevent the accomplishment of a critical mission objective. Safety and mission-critical subsystems shall be designed to be fail-operational/fail-safe/restorable, as a minimum (except primary structure and pressure vessels in rupture mode and premature firing of pyrotechnics). This criteria applies

Item	Wt (lbs)	Vol (ft ³)	Dens lb/ft ³	Pressurized Modular(s)		Unpressurized Dry Cargo Carrier(s)		Std Equip Reckard		Cold Storage(s)		Animal Cages(s)		Log Storage(s) (10 lb/ft ³ cap.)		Water Tanks		Log Storage(s) (20 lb/ft ³ cap.)		Growth Allow.	Destination
				(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)		
• Food																					
Ambient	1079	47	22.96	1079	47														1079	47	HSO
Refrigerated	719	31	23.19	719	31					219	31										HSD
Frozen	1439	83	22.84	1439	83					1439	83										HSD
• Patient Support																					
Hygiene	288	44	6.55	288	44														288	44	HSD
Clothing	247	84	2.94	247	84														247	84	HSD
Health Maint.	39.7	1.3	30.54	39.7	1.3														39.7	1.3	HSD
• Station Support																					
Maintenance	236.3	18.5	12.77	236.3	18.5														236.3	18.5	HSD
Waste Management	122	3	40.67	122	3														122	3	HSD
TOTALS	4170	291.8		4170	291.8					2158	94								2012	197.8	

- (1) Cargo Used in Pressurized Environment
- (2) Cargo Used in Unpressurized Environment
- (3) Equipment Rack Envelope per Figure 2-17 of CRB000148 (74.5" High) did 66%₂, 23.0 h¹ of usable cargo volume.
- (4) Container Envelope same as the functional unit envelope per Figure 2-16 of CRB000148 (60.8" High) did 64%₂, 25.6 h¹ of usable cargo volume.

FIGURE 6.5.1.8-1 90-DAY REQUIREMENTS-CREW SUPPORT-DRY CARGO-UP-
IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

FIGURE 6.5.1.8-1 90-DAY REQUIREMENTS-CREW SUPPORT-DRY CARGO-UP-
IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

FIGURE 6.5.1.8-2 90-DAY REQUIREMENTS-CREW SUPPORT-DRY CARGO-DOWN-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO CARRIER)

1) Cargo Used in Pressurized Environment
2) Cargo Used in Unpressurized Environment
3) Equipment Rack Envelope per Figure 2-17 of C880000148 (74.5" high) did 6/6/6. 23 0 n1 of useable cargo volume.
4) Container Envelope same as the functional unit envelope per Figure 2-16 of C880000148 (80 0" high) did 6/6/6. 25 0 n1 of useable cargo volume.

Sheet 307

Item	Wt (lbs)	Vol (ft ³)	Dens lb/ft ³	Pressurized Module(1)		Unpressurized Dry Cargo Carrier(2)		Std Equip Racks(3)		Cold Storage(4)		Animal Cages(4)		Log Stowage(4) (10 lb/ft ³ Cap.)		Water Tanks		Log Stowage(4) (20 lb/ft ³ Cap.)		Growth Allow	Destination
				(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)		
• Station Support																					
Maint Work Station	9.0	1.3	6.92	9.0	1.3													9.0	1.3		HSO
Tech Doc	52.4	1.0	52.4	52.4	1.0													52.4	1.0		HSO
Trace Cont Control	27.6	0.9	30.67	27.6	0.9													27.6	0.9		HSO
• Spares																					
ECLSS	1063	75.5	14.08	1063	75.5													1063	75.5		HSO
DMS	517	63	8.21	517	63													517	63		HSO
Thermal	1031	19	54.26	1031	19													1031	19		HSO
Communication	102	3	34.0	102	3													102	3		HSO
Structures	177	12.8	13.83	177	12.8													177	12.8		HSO
HSO	524	13	40.31	524	13													524	13		HSO
Truss	470	12	39.17			470	12							470	12.0						Truss
Propulsion	182	1.1	165.45			182	1.1							182	1.1						Prop
Power System																					Pow. Sys.
Solar Dynamics Photovoltaic	479	147	3.26											479	147						
PMAD	469	16	29.31	469	16													469	16		
• EVA Support																					
Consumables	544	9.1	59.78	544	9.1																HSO
Limited Life Items	1108	28	39.57	1108	28													1108	28		HSO
TOTALS	6755	402.7		5624	242.6	1131	160.1							1131	160.1			5624	242.6		

(1) Cargo Used in Pressurized Environment

(2) Cargo Used in Unpressurized Environment

(3) Equipment Rack Envelope per Figure 2-17 of CR88000148 (74.5" high) dtd 6/6/6. 23.0 ft³ of useable cargo volume.

(4) Container Envelope same as the functional unit envelope per Figure 2-16 of CR88000148 (80.0" high) dtd 6/6/6. 25.0 ft³ of useable cargo volume.

FIGURE 6.5.1.8-3 90-DAY REQUIREMENTS-STATION SUPPORT-DRY CARGO-
UP-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

Item	Wt (lbs)	Vol (ft ³)	Dens lb/ft ³	Pressurized Module(1)		Unpressurized Dry Cargo Carrier(2)		Std Equip Racks(3)		Cold Storage(4)		Animal Cages(4)		Log Storage(4) (10 lb/ft ³ Cap.)		Water Tanks		Log Storage(4) (20 lb/ft ³ Cap.)		Growth Allow	Origin
				(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)		
• Station Support																					
Trace Cont. Control	27.6	0.9	30.67	27.6	0.9													27.6	0.9		HSO
• Spares																					
ECLSS	1063	75.5	14.08	1063	75.5													1063	75.5		HSO
DMS	517	63	8.21	517	63													517	63		HSO
Thermal	1031	19	54.26	1031	19													1031	19		HSO
Communication	102	3	34.0	102	3													102	3		HSO
Structures	177	12.8	13.83	177	12.8													177	12.8		HSO
HSO	524	13	40.31	524	13													524	13		HSO
Truss	470	12	39.17			470	12.0							470	12.0						Truss
Propulsion	182	1.1	165.45			182	1.1							182	1.1						Prop
Power System																					Pow. Sys.
Solar Dynamics Photovoltaic	479	147	3.26			479	147							479	147						
PMAD	469	16	29.31	469	16													469	16		
• EVA Support																					
Consumables	544	9.1	59.78	544	9.1													544	9.1		HSO
Limited Life Items	1108	28	39.57	1108	28													1108	28		HSO
TOTALS	7131	407.4		6000	247.3	1131	160.1							1131	160.1	437.4	7	5562.6	240.3		

(1) Cargo Used in Pressurized Environment

(2) Cargo Used in Unpressurized Environment

(3) Equipment Rack Envelope per Figure 2-17 of CR88000148 (74.5" high) dtd 6/6/6. 23.0 ft³ of useable cargo volume

(4) Container Envelope same as the functional unit envelope per Figure 2-16 of CR88000148 (80.0" high) dtd 6/6/6. 25.0 ft³ of useable cargo volume.

FIGURE 6.5.1.8-4 90-DAY REQUIREMENTS-STATION SUPPORT-DRY CARGO-
DOWN-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

FIGURE 6.5.1.8-4 90-DAY REQUIREMENTS-STATION SUPPORT-DRY CARGO-
DOWN-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

Item	Wt (lbs)	Vol (ft ³)	Dens lb/ft ³	Pressurized Module(1)		Unpressurized Dry Cargo Carrier(2)		Std Equip Racks(3)		Cold Storage(4)		Animal Cages(4)		Log Storage(4) (10 lb/ft ³ Cap.)		Water Tanks		Log Storage(4) (20 lb/ft ³ Cap.)		Growth Allow	Destination
				(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)		
• USL																					
Payload/S&C CO	1890	105	18.0	1890	105			1890	105												MTL
S&C Spares	219	11.1	19.7	219	11.1													219	11.1		MTL
Payload Spares	295	22.6	13.1	295	22.6													295	22.6		MTL
Unique Subsys Sp.	536	10.2	52.6	536	10.2													536	10.2		MTL
General Lab Dispos.	250	6.0	41.7	250	6.0													250	6.0		MTL
Solids/Samples	836	9.8	85.3	836	9.8													836	9.8		MTL
Cleaning Fluid	32	.5	62.4	32	.5													32	.5		MTL
H ₂ O	350	5.6	62.4	350	5.6											350	5.6				MTL
Plant/Animal																					
Dry Weight	495.4	22.3	22.2	495.4	22.3													495.4	22.3		MTL
Live Weight	623.5	50.6	12.3	623.5	50.6							623.5	50.6								MTL
Human Research																					
Dry Weight	71	2.0	35.3	71	2.0													71	2.0		Columbus
• Columbus																					
Lab Payload	3678	142	25.90	3678	142			3678	142												Columbus
Lab Spares	467	31	15.06	467	31													467	31		Columbus
• JEM																					
Dry Weight	495.4	21.8	22.2	495.4	21.8													495.4	21.8		JEM
Live Weight	623.5	50.1	12.3	623.5	50.1							623.5	50.1								JEM
H ₂ O	60	.96	62.4	60	.96											60	.96				JEM
• COP																					
PL Resupply (ESA)	7402	1045	7.1			7402	1045											7402	1045		COP
ORU's	1414	95	14.9			1414	95											1414	95		COP
• Attached PL	246	6.2	39.7			246	6.2											246	6.2		Attach PL
• OMV Accom.	92	6.6				92	6.6											92	6.6		OMV Accom
TOTALS	20075.8	1644.36		10921.8	491.56	9154	1152.8	3568	247			1247	100.7	9154	1152.8	410	6.56	3696.8	137.3		

(1) Cargo Used in Pressurized Environment
(2) Cargo Used in Unpressurized Environment
(3) Equipment Rack Envelope for Figure 2-17 of C88000148 (74.5" High) dtd 6/6/6. 23.0 ft³ of useable cargo volume
(4) Container envelope same as the functional unit envelope per Figure 2-16 of C88000148 (80.0" High) dtd 6/6/6. 25.0 ft³ of useable cargo volume.
(5) Carried in Berthing Adaptor

FIGURE 6.5.1.8-5 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-DRY CARGO-
UP-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

FIGURE 6.5.1.8-5 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-DRY CARGO-
UP-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

90 DAY REQUIREMENTS - CUSTOMER SUPPORT - DRY CARGO - DOWN - PER CR NO. BM010026A
(Pressurized Module & Unpressurized Dry Cargo Carrier)

Item	Wt. (lbs)	Vol (ft ³)	Dens lb/ft ³	Pressurized Module(1)		Unpressurized Dry Cargo Carrier(2)		Std Equip Racks(3)		Cold Storage(4)		Animal Cages(4)		Log Stowage(4)		Water Tanks		Log Stowage(4)		Growth Allow	Origin
				(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)	(lbs)	(ft ³)		
• USL																					
Payload/SCCO	1890	105	18.0	1890	105			1890	105												MTL
S&C Spares	219	11.1	19.7	219	11.1													219	11.1		MTL
Payload Spares	295	22.6	13.1	295	22.6													295	22.6		MTL
Unique Subsys. Sp.	536	10.2	52.6	536	10.2													536	10.2		MTL
General Lab Dispose	250	6.0	41.7	250	6.0													250	6.0		MTL
Products	836	9.8	85.3	836	9.8													836	9.8		MTL
Plant/Animal & Human Research																					
Dry Weight	50	26.6	1.9	50	26.6													50	26.6		Columbus
Live Weight	584	26.6	22	584	26.6							584	26.6(5)								Columbus
Waste	428.4	20.5	20.9	428.4	20.5													428.4	20.5		Columbus
Frozen Weight	148.3	1.0	148.3	148.3	1.0					148.3	1.0										Columbus
• Columbus																					
Lab Payload	3678	142	25.90	3678	142			3678	142												Columbus
Lab Spares	467	31	15.06	467	31													467	31		Columbus
• JEM																					
Dry Weight	50	26.6	1.9	50	26.6													50	26.6		JEM
Live Weight	584	26.6	22	584	26.6							584	26.6(5)								JEM
Waste	406	19.0	21.37	406	19													406	19		JEM
Frozen Weight	66.3	.5	132.6	66.3	.5					66.3	.5										JEM
• COP																					
P/L Retupply	7402	1045	7.1			7402	1045														
ORU's	1414	95	14.9			1414	95							7402	1045						COP
• Attached P/L	246	6.2	39.7			246	6.2							1414	95						COP
• OMV Accom.	92	6.6	13.9			92	6.6							246	6.2						Attach P/L
TOTALS	19542	1637.9	-	10488	485.1	9154	1152.8	5568	247	214.6	1.5	1168	53.2	9154	1152.8			3537.4	183.4		OMV Accom

- (1) Cargo Used In Pressurized Environment
(2) Cargo Used In Unpressurized Environment
(3) Equipment Rack Envelope per Figure 2-17 of CRB000148 (74.5" high) dtd 6/6/6. 23.0 ft³ of useable cargo volume
(4) Container Envelope same as the functional unit envelope per Figure 2-16 of CRB000148 (80.0" high) dtd 6/6/6. 25.0 ft³ of useable cargo volume.
(5) Carried in the Berthing Adaptor

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FIGURE 6.5.1.8-6 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-DRY CARGO-
DOWN-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

FIGURE 6.5.1.8-6 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-DRY CARGO-
DOWN-IOC PRIME (PRESSURIZED MODULE AND UNPRESSURIZED DRY CARGO
CARRIER)

Item	Weight (lbs)	Vol (ft ³)	Dens lb/ft ³	Fluids Carrier		Propellant Carrier		Growth Allow.	Destination
				(lbs)	(ft ³)	(lbs)	(ft ³)		
• MTL									
Helium	4	.2	2.82	4	.2				MTL
Oxygen	20	1.1	71.17	20	1.1				MTL
Nitrogen	314	5.3	50.44	314	5.3				MTL
Argon	56	1.9	86.96	56	1.9				MTL
• JEM									
Nitrogen	11	1.3	50.44	11	1.3				JEM
• Satellite Serv.									
N ₂ H ₄ (Spartan)	825	13.2	62.5			825	13.2		SAT
N ₂ H ₄ (GRO)	338	5.4	62.5			338	5.4		SAT
• COP									
MMH	960	18.11	40.8			960	40.8		COP
N ₂ O ₄	1584	18.21				1584			
• OMV									
Nitrogen	400	8.0	50.44	400	8				OMV
TOTALS	4513	77.2		805	17.8	3707	59.4		

FIGURE 6.5.1.8-8 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-FLUIDS-UP-
IOC PRIME (ECLSS AND LAB FLUIDS AND PROPELLANTS CARRIERS)

FIGURE 6.5.1.8-8 90-DAY REQUIREMENTS-CUSTOMER SUPPORT-FLUIDS-UP-
IOC PRIME (ECLSS AND LAB FLUIDS AND PROPELLANTS CARRIERS)

during all operational phases except initial assembly and maintenance. For applicable subsystems, some degraded performance following the first failure is not precluded by the fail-operational/fail-safe requirement. During assembly and maintenance, critical SSPE subsystems shall be fail-safe as a minimum. Other SSPE subsystems and ground support hardware shall be designed to be fail-safe/restorable. Subsystems in pressurized modules shall be able to return to normal operation after the module has lost pressure on-orbit and been repressurized.

6.5.1.10.2 Redundancy

a. Redundancy verification

Redundant functional paths of subsystems shall be designed to permit verification of their operational status in flight without removal of Orbital Replacement Units (ORUs).

b. Redundancy management.

SSPE subsystems design shall provide redundancy management and redundancy status to the flight or ground crew, as applicable. Safety and mission critical subsystems shall be designed such that no single instrumentation failure shall cause the loss of a redundant functional path.

6.5.1.10.3 Failure Propagation

Subsystem design shall be such that one failure does not cause additional failures.

6.5.1.10.4 Separation of Redundant Paths

Alternate or redundant functional paths shall be separated or protected such that any event which causes the loss of one functional path will not result in the loss of the alternate or redundant functional path(s).

6.5.1.11 Safety

The safety programmatic requirements shall be as specified in "Product Assurance Requirements for the Space Station Program," (J8400001). The SSPEs and ground systems shall meet the safety design requirements specified herein.

The following safety requirements are applicable to all SSP systems, subsystems, and operations. These requirements apply under worst-case natural and induced environments.

6.5.1.11.1 Order of Design Precedence

The Space Station design shall reflect the following order of precedence: (1) elimination of hazards by removal of hazardous sources and operations by appropriate design measures; (2) prevention of hazards through the use of safety devices or features; (3) control of hazards through the use of warning devices, special procedures, and/or emergency devices; and (4) minimization of hazards through a maintainability program and adherence to an adequate maintenance and repair schedule(s).

6.5.1.11.2 Margin/Factors-of-Safety

All structures of the SSPE shall have the positive margins of safety (MS) for all load conditions. The following relation Defines MS:

$$MS = \frac{\text{allowable load}}{\text{Limit Load} \times \text{Factor of Safety (FS)}} - 1.0$$

Factors of safety are assumed multiplicative constants applied to maximum expected or limit loads that occur during any phase of the hardware from manufacture

throughout its operational life to account for uncertainties in load definition, material properties, dimensional discrepancies, etc.

The design of structure of the SSPE shall use the appropriate factors of safety defined in Table 6.5.1.11.2-I.

6.5.1.11.3 General Safety Requirements

6.5.1.11.3.1 Safing

The following capabilities shall be provided by the Space Station:

- a. Detection, containment and control shall be provided for emergencies such as fires, toxic contamination, depressurization, malfunction of mechanical systems and rotating equipment, or structural damage. Specific procedures shall be provided for each emergency to restore a safe operating condition.
- b. Isolation of any module containing confined hazardous or toxic materials from the remainder of the Space Station. Emergency conditions requiring isolation of a module shall be defined on a case-by-case basis.

6.5.1.11.3.2 System failure notification

All failures of critical SSPE systems shall be annunciated to the flight and/or ground crew.

6.5.1.11.3.3 Pressure vessels

a. Storage containers

Potentially explosive containers shall be located outside of habitable areas, shall be isolated and protected so

that failure of one will not propagate to others, and shall be designed to leak-before-rupture. Specific safety requirements and handling procedures shall be provided for all potentially hazardous materials.

- b. Pressurized modules – All pressurized modules shall be designed to leak-before-rupture criteria. A wall puncture due to an accident or collision shall not result in rupture. Conservative factors of safety shall be provided where critical single-failure-point modes of operation cannot be eliminated.
- c. Pressurized lines and fittings – Pressurized lines and fittings shall meet specified ultimate factors of safety. Other pressure system components not considered pressure vessels, lines, and/or fittings shall have an ultimate factor of safety equal to or greater than 2.5.
- d. Accessibility – All walls, bulkheads, hatches, and seals where integrity is required to maintain pressurization shall be accessible for inspection, maintenance, or repair by shirt-sleeved crewmembers.
- e. Depressurization capability – Systems, Subsystems, or equipment located in Space Station pressurized volumes designed to withstand decompression and repressurization shall be capable of tolerating the differential pressure and depressurized condition without resulting in a hazard.

TABLE 6.5.1.11.2-I FACTORS OF SAFETY

Components	Minimum Factors of Safety (FS) Ultimate
General structure	1.5*
Pressurized manned compartments	2.0
Pressure vessels	1.5
Pressurized lines and fittings	
Less than 1.5-in. -diameter	4.0
1.5-in. -diameter or greater	2.0
Tempered or mechanically precompressed Initial FS panes	2.0**
* General structure shall be designed with a yeild factor of safety (FS) no less than 1.1. Protoflight hardware must be designed to not yeild when subjected to validation loads.	
** Glass shall be designed such that the limit tensile stresses on the glass do not exceed the surface compression of the glass, and thus glass does not lose strength with time.	

6.5.1.11.3.4 Hazardous Accumulating of Fluids

Provisions shall be made to prevent hazardous accumulations of gases or liquids within the Space Station. Detection, monitoring, and control of hazardous gases or vapors shall be required in critical areas and closed compartments.

6.5.1.11.3.5 Drains, Vents, and Exhaust Ports

Drains, vents, and exhaust ports shall prevent fluids, gases and/or vapors, and flames from creating hazards to personnel, vehicles, or equipment.

6.5.1.11.3.6 Propellants

Safety requirements applicable to the on-orbit servicing of solid propellant upper stages, reaction control systems using monopropellants, other hyperbolics, and/or cryogenics are under development and will be provided during the system definition phase.

6.5.1.11.3.7 Exposed surface temperatures

Exposed surfaces within modules shall not exceed a temperature of 450C (1130F) (with a design goal of 420C (1050F) and a low temperature less than 160C (610F).

6.5.1.11.3.8 Explosive devices

Provisions shall be made for arming explosive devices as near to the time of expected use as feasible. Provisions shall be made to promptly disarm explosive devices when no longer in use. All pyrotechnic devices shall meet the design requirements specified in the document "Space Shuttle System Pyrotechnic Specification", JSC-08060 (J8400004).

6.5.1.11.3.9 Battery Location Design

Batteries shall be isolated and/or provided with safety venting systems and/or explosion protection. In addition, thermal control and charging/discharge protection for batteries shall be provided, where applicable.

6.5.1.11.3.10 Exposed Power Leads

The crew shall not be exposed to electrical power leads. Ground-fault protection shall be provided for circuitry or power distribution busses directly accessible by the flight crew.

6.5.1.11.3.11 Fire Suppression

Capability shall be provided for detecting and extinguishing any fire in Space Station habitable volumes. Interior walls and secondary structures shall be self-extinguishing. Fire extinguishers shall be compatible with the ECLSS and shall be non-toxic and not produce toxic by-products.

6.5.1.11.3.12 Spacecraft with RTGs

Design of SSPE subsystems shall safely accommodate the assembly, storage and servicing of spacecraft which have Radioisotope Thermoelectric Generators (RTGs).

6.5.1.11.3.13 Emergency equipment

Emergency life support, damage assessment, and medical equipment shall be readily accessible to the crew.

6.5.1.12 Materials

The Space Station materials requirements for hazardous materials, flammability and offgassing are as follows:

a. Hazardous materials.

- (1) General. The use of hazardous materials shall be minimized; those used shall meet the applicable requirements specified in NHB 8060.1B, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials Used in Environments that Support Combustion" (J8400003).
- (2) Material radiation effects. Materials and components subject to insidious degradation in the Space Station ionizing environment shall not be used where that degradation can cause or contribute to any crew hazards.
- (3) Mercury. The use of mercury or its compounds shall be restricted.

b. Habitable volume materials which are used in habitable volumes of the Space Station shall meet the requirements of NHB 8060.1B (J8400003). The SSP requirements for materials and process control will be established by NASA prior to Contract Start Date (CSD). In the interim, SE-R-0006, "General Specifications, NASA JSC Requirements for Materials and Processes" (J8400016) and Marshall Space Flight Center (MSFC) Document 57D506B, "Standard Materials and Process Control" (J8400041) shall be utilized for the appropriate requirements.

c. Flammable materials exposed to the ambient atmosphere of Space Station habitable volumes shall be separated to prevent flame propagation paths. Similarly, separation of flammable

materials from potential ignition sources is required to the maximum extent possible. Minimizing the use of flammable materials shall be the preferred means of hazard reduction. Materials are considered to be non-flammable or self-extinguishing if they meet the applicable flammability requirements of NHB 8060.1B (J8400003). Reference(s) for flammability testing and material selection guidelines shall be provided at CSD.

d. Materials used in Space Station habitable volumes shall meet the requirements of NHB 8060.1B (J8400003) for toxic outgas constituents in the lowest operating pressure to which they may be exposed.

e. Equipment or materials sensitive to contamination shall be handled in a controlled environment. Fluids and materials shall be compatible with the combined environment in which they are employed.

- (1) Materials exposed to space vacuum shall meet the requirements of SP-R-0022A (J8400042) for vacuum outgassing.
- (2) Metallic materials which are exposed/used in the habitable volumes shall be selected and controlled by the criteria of MSFC Spec. 522A "Design Guidelines for Controlling Stress Corrosion Cracking" (J8400043).
- (3) Exterior materials shall consider atomic oxygen effects.

6.5.1.13 Malfunction Control

Override capability - the crew must be able to override any automatic safing or switchover capability of functional paths. All overrides shall be two-step operations with positive feedback to the initiator that reports the impending results of the override command prior to the acceptance of an execute command. Separable functional paths shall be used to prevent single failures from causing both an unintended auto switchover and the inability to override it.

6.5.2 System Configuration

The Logistics System consists of four major elements. These are a Pressurized Module, an Unpressurized Cargo Pallet, a Propellant Carrier and an Unpressurized Fluids Section. A brief description of each of the elements follows.

The Pressurized Module is fabricated from Common Module hardware. It has the same skin, support rings, internal payload support structure, body mounted meteoroid shield, one end dome, berthing port, hatch, trunions and keel pin. The difference between it and the Common Module is, it contains two skin segments, three rings, one end dome is provided with a 2387.6mm (94 in) diameter opening fitted with a ground removable cover and only one hatch. Trunion and keel fittings are provided.

The Unpressurized Cargo Pallet is an 2438.4mm (96 in) foot long cylindrical segment. Equipment and storage racks and bins are mounted the same as those in the pressurized module. Subsystems are not provided except for an input to the Inventory Management system by means of a bar code reader.

The Propellant Carrier is a stand-alone unit designed to transport the orbiting

platform, satellite, and Space Station propellants. It contains all tanks, plumbing, valves, disconnects and heaters required for transport and transfer of propellants to the Space Station integrated Fluids Management system. This carrier is equipped with trunion and keel fittings and can be handled on the ground and in orbit independently of other logistics elements. Twenty eight volt DC power is provided by the STS to the carrier during launch operations. On-station, 20 KHz station power is provided to the carrier.

The Fluids Segment contains tanks and plumbing necessary to transport the ECLSS fluids and certain laboratory gas. The segment is equipped with ring frames which can connect to the unpressurized cargo pallet allowing the two units to be transported in the STS as one unit. The segment can also be equipped with trunion and keel fittings to allow transport independent of other elements.

6.5.2.1 Pressurized Module

The Logistics Systems pressurized element is made from common module elements consisting of a stiffened welded aluminum structure with conical end bulkheads. The module has a berthing port at one end with a closure hatch hinged for inward opening. The opening is 1270 mm (50 in) square with 304.8mm (12 in) corner radii.

The primary rings are welded integrally to the pressure shell and the two end rings form the junction at the bulkhead-to-shell joint. The external and internal ring flanges provide attach points for the thermal and meteoroid protection and for the payload support structure.

The meteoroid, debris and radiation protection subsystem will use common module hardware. Protection to the module cylindrical portion is provided by the pressure shell, multilayer insulation, and the

outer 1.016mm (0.04 in) meteoroid panel. This configuration provides for a 127mm (5 in) standoff between the meteoroid panel and the pressure shell. Stiffened panels provide protection at the module ends.

Trunion and keel pin fittings for attaching the module within the orbiter payload bay are located on the primary rings as shown in Figure 6.5.2.1-1. These fittings and pins are common module parts. The selected payload bay attach points must permit the cargo to fall within the center of gravity and weight envelope specified for orbiter payload bay cargo.

The internal configuration of the Pressurized Module is shown in Figures 6.5.2.1-2 and 6.5.2.1-3.

6.5.2.2 Unpressurized Cargo Pallet

The unpressurized cargo pallet is a cylindrical section 2438.4 mm (96 in) long and 4165.6 mm (164 in) in diameter. The configuration of the pallet is shown in Figure 6.5.2.2-1. It is used to transport cargo which does not require environmental control for transport or storage.

6.5.2.3 Propellant Carrier

The propellant carrier configuration is shown in Figure 6.5.2.3-1. It is designed to transport all propellant to the Space Station.

6.5.2.4 Unpressurized Fluids Segment

The unpressurized fluids segment is used to transport and store all non hazardous fluids except water. The segment consists of a five foot long structure which contains six 1143 mm (45 in) diameter tanks for liquid nitrogen and helium, and two 812.8 mm (32 in) diameter tanks for liquid oxygen and Argon. The segment forward and

aft ring frames are common module hardware and mate directly with the pressurized module and with the unpressurized cargo carrier. Figure 6.5.2.4-1 shows the configuration of the segment.

6.5.2.5 Outfitting

The pressurized Logistics Module shall be provided, complete with all subsystems as defined in Logistics Elements Contract End Item Specification SS-SPEC-0003. Outfitting of this module will consist of the development and installation of racks, an inventory management system, and a transport status system.

Outfitting of the unpressurized carriers includes the design, development, and production of the various carriers. Requirements for the carriers are included in Logistics Elements Contract End Item Specification SS-SPEC-0003.

6.6 Vehicle Accommodations

This section summarizes requirements and general constraints, and provides some ground rules for preliminary design. Items covered in this section are: 1) OMV Accommodations 2) OTV Accommodations and 3) Smart Front End.

6.6.1 OMV Accommodations

6.6.1.1 Space Station OMV

The baseline OMV configuration used for Space Station OMV Accommodations is described in the January, 1985, revision of the NASA document Orbital Maneuvering Vehicle Preliminary Definition Study prepared by the Program Development office of Marshall Space Flight Center. The reference OMV configuration was updated with information received from the NASA OMV Program Office in September, 1985. The update, which includes the substitu-

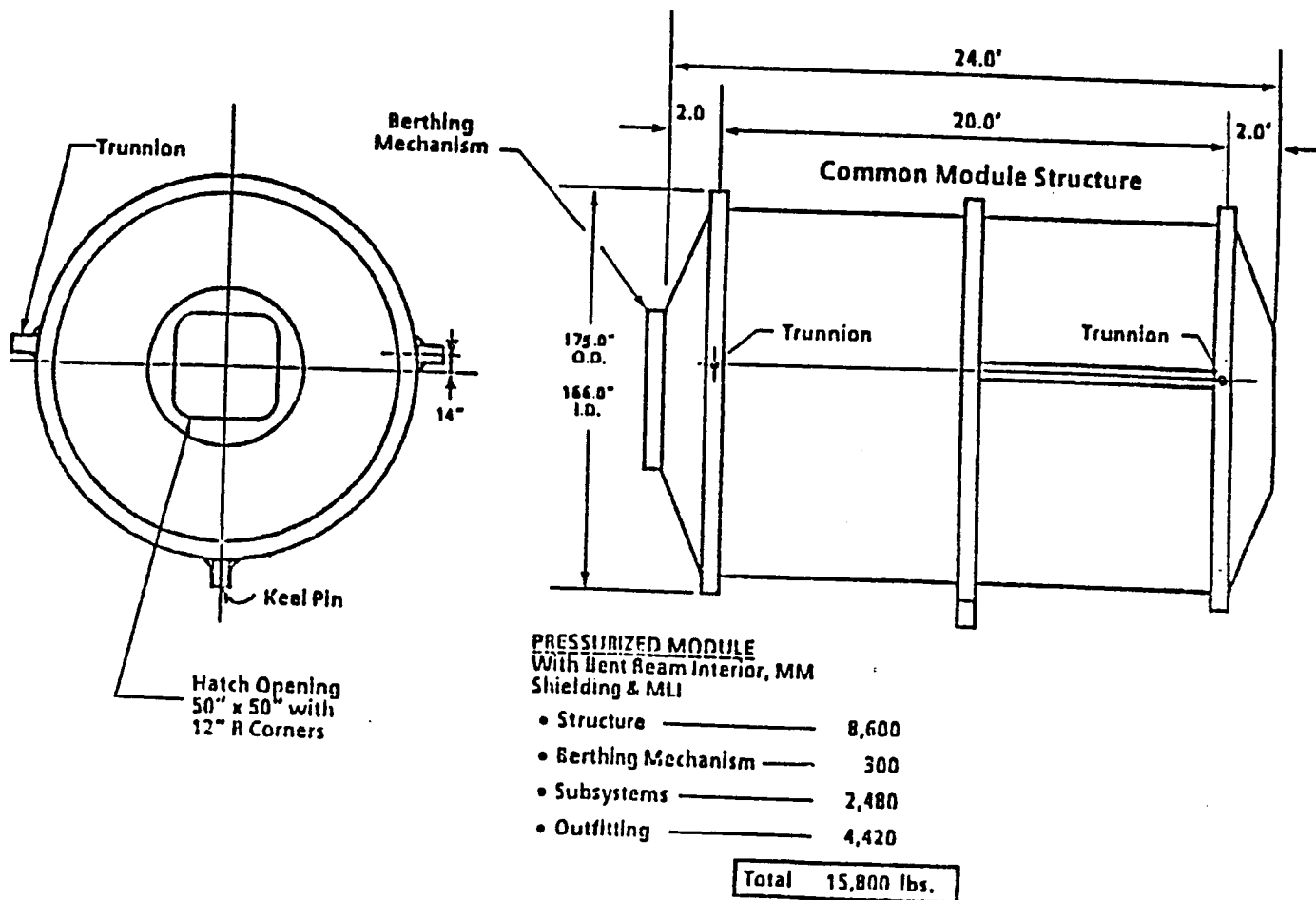


FIGURE 6.5.2.1-1 PRESSURIZED MODULE

- **Stowage Envelope**
- **4 Standoff Support Structure**

- **Stowage Envelope**
- **4 Standoff Support Structure**

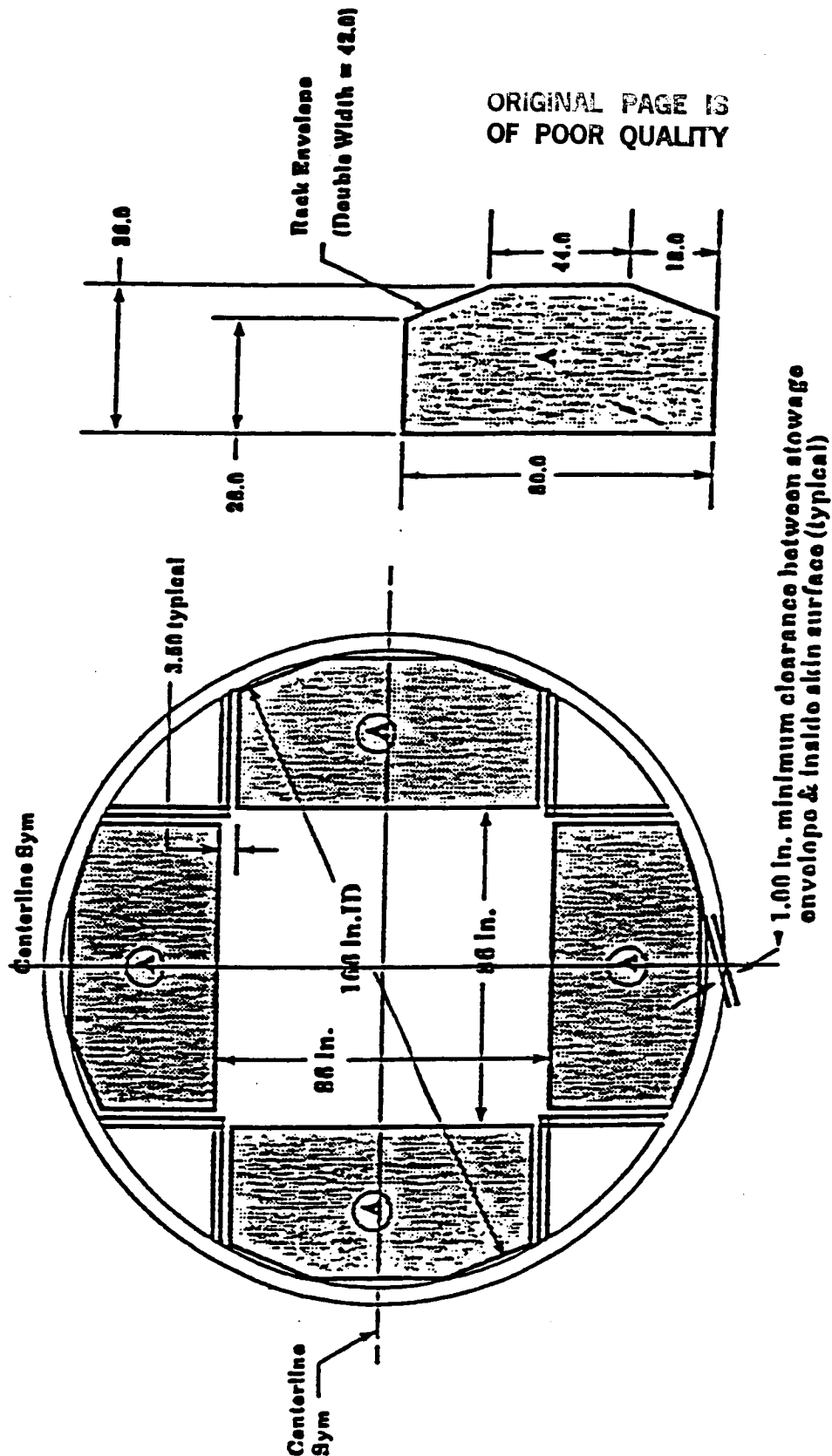


FIGURE 6.5.2.1-2 PRESSURIZED MODULE

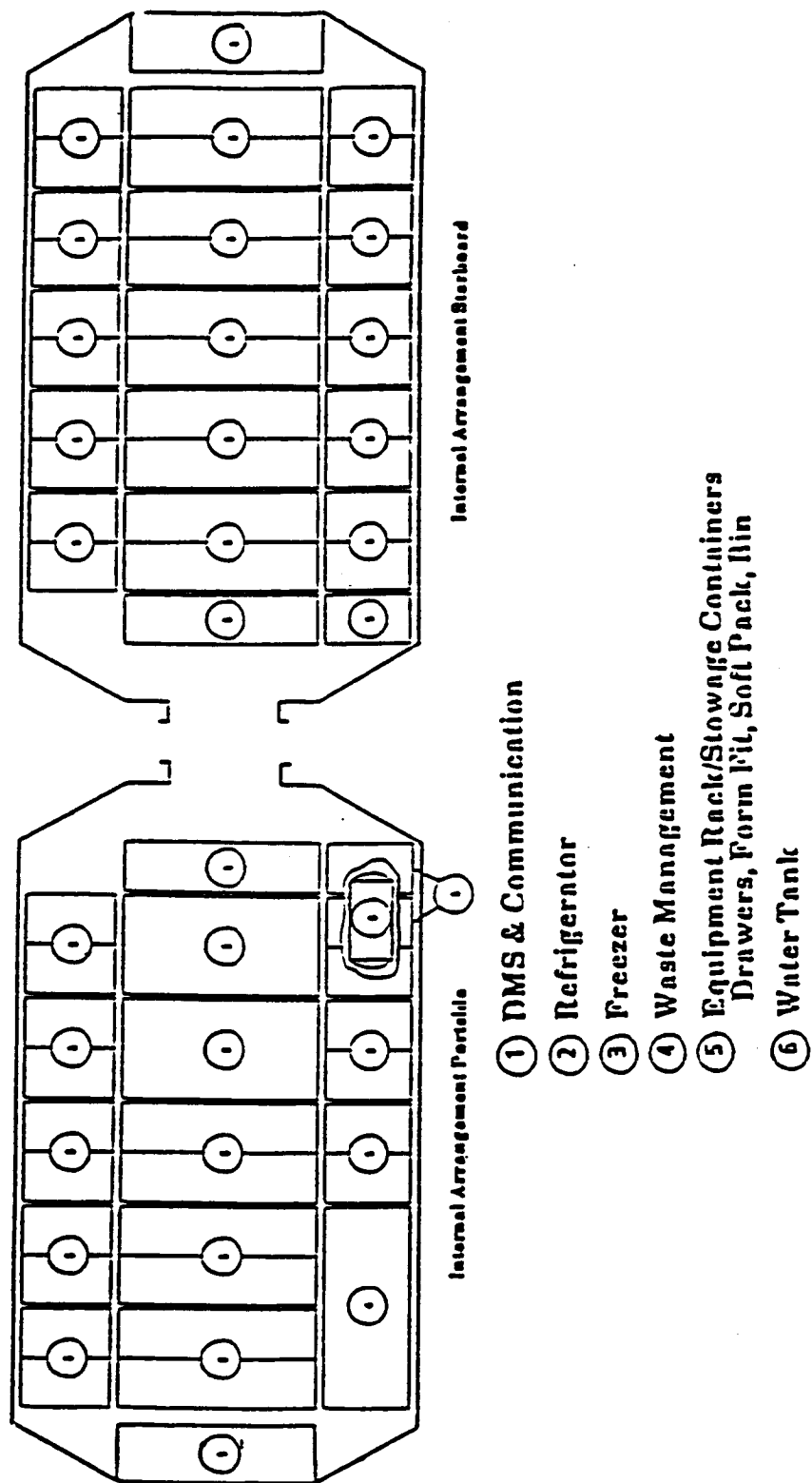
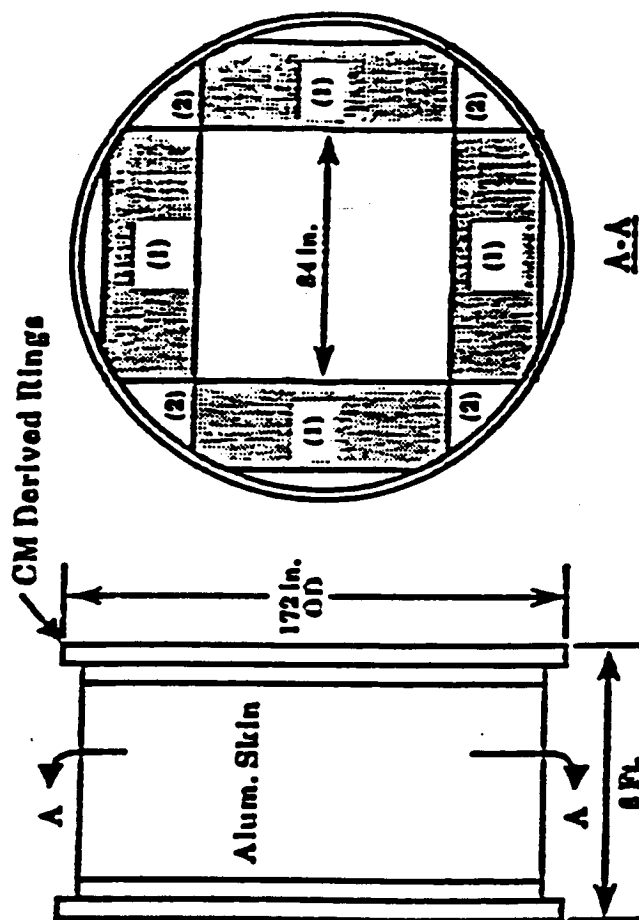


FIGURE 6.5.2.1-3 PRESSURIZED MODULE

FIGURE 6.5.2.1-3 PRESSURIZED MODULE



Note:
For stand-alone carrier
concept add four
trunnions and keel pin

Stowage Capacity
Based on 75% Container Efficiency

(1) Racks: 42 in. x 36 in. x 80 in. - 8 @ 51 CF = 408 CF
(2) Form Fit/Soft Pack - 4 @ 18 CF = 72 CF

Total 480 CF

FIGURE 6.5.2.2-1 UNPRESSURIZED DRY CARGO CARRIER

FIGURE 6.5.2.2-1 UNPRESSURIZED DRY CARGO CARRIER

SEPARABLE FOR OMV
ONLY TRANSPORT

FLUID TANK BREAKDOWN

NAV SUPPLY

- 2 68"Ø SPHERICAL
PROPELLANT TANKS
- 1 42"Ø SPHERICAL
PRESSURANT TANK
- 1 30"Ø SPHERICAL
COLD GAS TANK

SPACE STATION SUPPLY

- 1 72"Ø SPHERICAL
PROPELLANT TANK
- 1 24"Ø SPHERICAL
PRESSURANT TANK

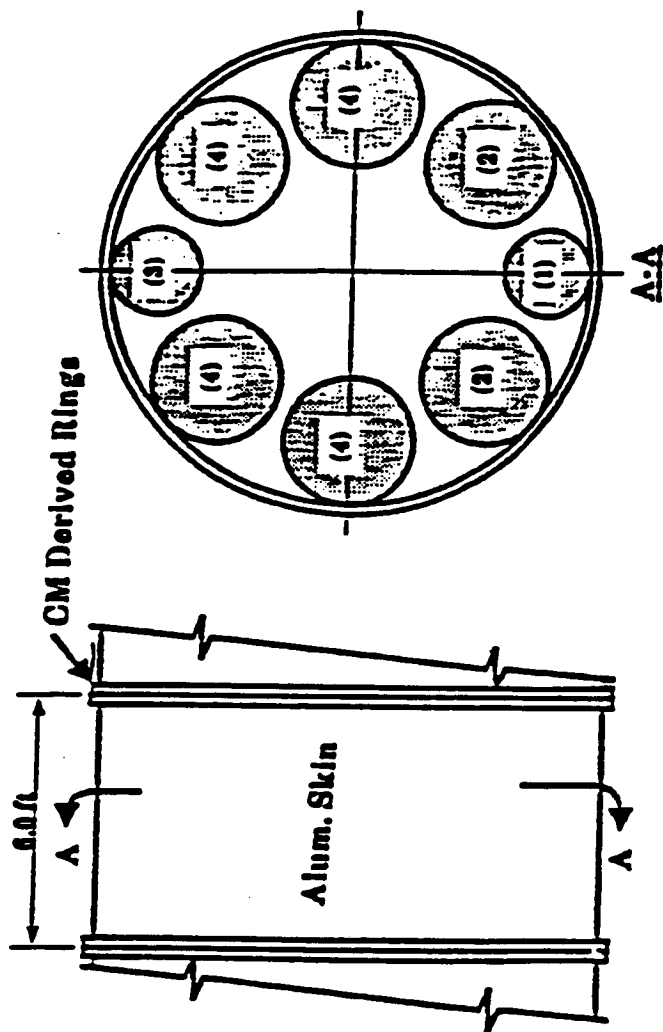
TRUSSING PIN (4)

KEEL PIN

STS PAYLOAD BAY

FIGURE 6.5.2.3-1 PROPELLANT CARRIER

FIGURE 6.5.2.3-1 PROPELLANT CARRIER



Note: For stand-alone carrier concepts add four trunnions and keel pin

Fluid/Gas	Characteristics	Tank	
		Qty	ID
(1) LO ₂	Supercritical	1	32 in.
(2) LN ₂	Supercritical	2	45 in.
(3) Argon	Supercritical	1	32 in.
(4) He	Supercritical	4	45 in.
O ₂	Pure	TBD	TBD

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FIGURE 6.5.2.4-1 FLUIDS CARRIER

FIGURE 6.5.2.4-1 FLUIDS CARRIER

tion of Helium gas as pressurant, has been incorporated into this document. The baseline OMV configuration is presented in Figure 6.6.1.1-1. It is anticipated that the OMV configuration will change as the OMV program progresses.

The baseline OMV design is 4521.2 mm (178 in) in diameter x 939.8mm (37 in) thick. Its mass is 5810 kg (12808.8 lb) fully loaded. Of the reference weight, over 50%, or 3265 kg, is storable propellant contained within 4 oblate spheroid tanks. The propellants are a combination of Nitrogen Tetroxide and Monomethyl Hydrazine, 6500 kg of which is estimated to be the required SS storage capability. Separate tanks on the OMV hold 15 kg (33.07 lb) of the pressurant Helium gas, and 80 kg (176.4 lb) of the gaseous Nitrogen used for non-contaminating cold gas propulsion.

6.6.1.2 OMV Accommodations Reference Configuration Data

The following discussion of OMV Accommodations configurations depends in part upon the reference overall Space Station configuration. Primarily this concerns location of OMV Accommodations on the Space Station, but includes operational considerations such as any requirements for direct visual observation of OMV Accommodations activities, e.g., close proximity flight, docking, berthing, payload integration and vehicle inspection. The following data for OMV Accommodations is from reference configuration revisions supplied by NASA.

The station will have an OMV that will be used to deploy and retrieve free flying payloads and to perform in situ servicing using OMV kits. The station will have accommodations for the OMV such that the OMV can be maintained in space. The accommodations will consist of support structure, automated umbilicals, and an

orbital vehicle control console. The Accommodations have the capability to deploy, launch, capture, and berth the OMV by use of the Canadian MSCS.

6.6.1.3 OMV Accommodations Operations

The OMV is controlled from the Space Station when the vehicle is within Control Zone (CZ) 1 and 2. CZ 1 is the proximity operations zone and consists of a 1 KM diameter sphere centered about the Space Station. CZ 2 is a 75 KM cube centered at the Space Station. Figure 6.6.1.3-1 indicates a typical OMV operational scenario.

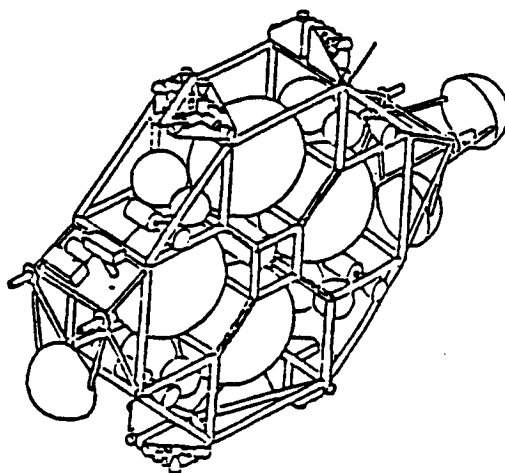
An estimate of total time required to support a single OMV mission is presented in Figure 6.6.1.3-2. Potential operations time overlap is shown, as is time required for operations performed only once per year.

An estimate of Space Station crew time required to support OMV mission operations is presented in Figure 6.6.1.3-3. Indication is made as to whether IVA or EVA is utilized for the various operations. Maintenance operations include those associated with EVA scheduling, internal repair activity, and equipment calibration and adjustments. Time listed for EVA indicates the time in which EVA is being performed - EVA at the Space Station will require two EVA crewmembers and one IVA crewmember simultaneously.

Table 6.6.1.3-I indicates the control functions that have been identified for OMV Accommodations. Indication is given as to whether the function is planned to be automated, performed manually, or be controlled in a hybrid manner.

Automated systems shall be incorporated into the control of Vehicle Accommodations elements. One automated system will be used to monitor the vehicles and their

MSFC Reference Design
Updated September 1986



Dimensions

178 X 178 X 50 inches

Weight

13,500 (loaded)

Propellant

7,200 lbs. MMH/NTO

180 lbs. GN₂ (cold gas)

30 lbs. HE (pressurant)

Functional Requirements

IOC

- Vehicle storage
- Flight operations
- Payload integration

Growth

- ORU changeout
- Fluid storage, conditioning transfer

FIGURE 6.6.1.1-1 BASELINE OMV SPACE STATION CONFIGURATION

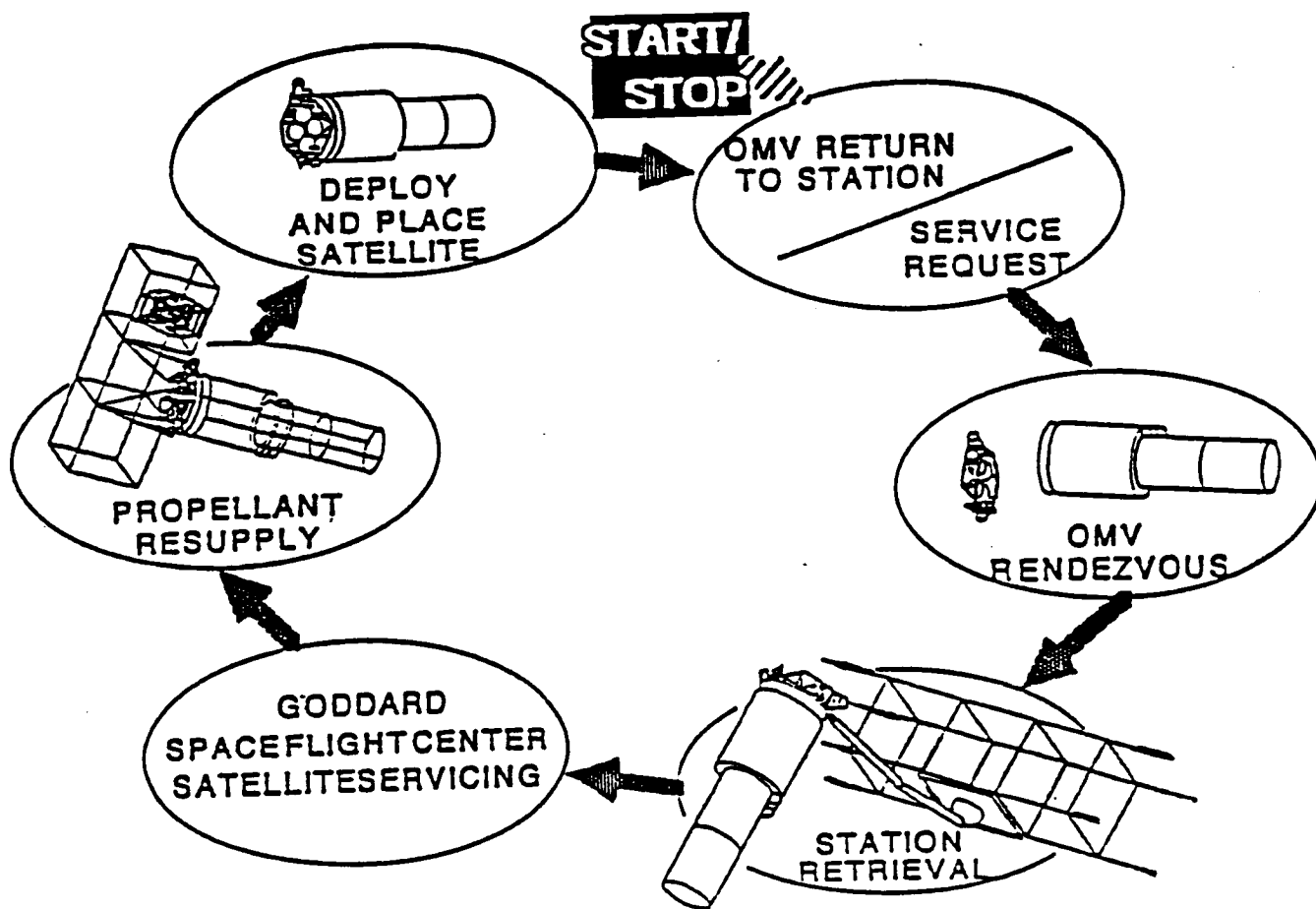


FIGURE 6.6.1.3-1 OPERATIONAL SCENARIO

Total Time = 50 hours

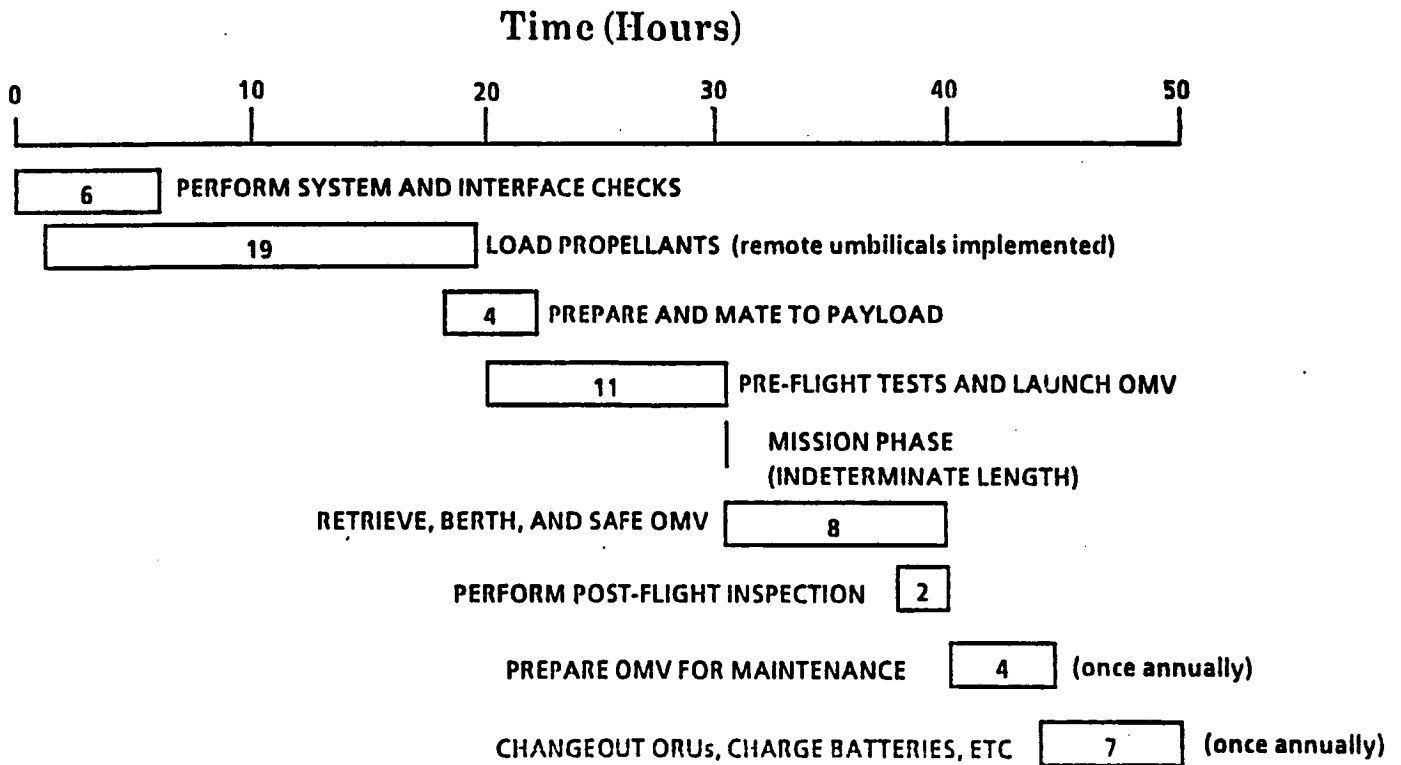


FIGURE 6.6.1.3-2 OMV ACCOMMODATIONS OMV SERVICING FLOW TIMELINE

OMV SERVICING CREW REQUIREMENTS

	<u>Crew Time Req'd</u> (hours per operation)
Propellant re-supply	2.75 (IVA)
Inspection	2 (IVA)
Battery charging	.25 (IVA)
System and interface checkout	4 (IVA)
Preflight Tests + Launch	5 (IVA)
Retrieval OPS	8 (IVA)
ORU changeout (if required)	2 (EVA) annually
Maint. OPS (if required)	9 (IVA) annually
Payload Handling (if required)	2 (EVA), 2 (IVA)

FIGURE 6.6.1.3-3 OMV ACCOMMODATIONS

TABLE 6.6.1.3-I OMV ACCOMMODATIONS CONTROL FUNCTIONS

	Automated	Manual
Flight Control		x
Docking and Berthing		x
Deployment		x
Payload Integration (mate/de-mate)		x
Subsystem Monitoring	x	
Subsystem Check-out	x	x
Fluid Resupply	x	x
ORU Change-out	x	x
Safing	x	x

accommodations. This system will track the subsystems' status, report any discrepancies, follow trendlines, supply summaries to the crew, and be able to reconfigure to redress anomalies. In addition to monitoring functions, fluid transfer and system checkout operations will also be highly automated. The automated functions will allow Space Station crew time to be spent more effectively.

6.6.1.3.1 Flight control

The OMV is piloted from the Space Station within CZ 2. The flight control is transferred between the Space Station OVCC and the GCS as the OMV reaches the boundaries of CZ 2. Within control zones 1 and 2 the vehicles are monitored by Ground Control Stations (GCS), which have the capability to assume control of the vehicles, should multiple Space Station system failures cause loss of control from orbit.

6.6.1.3.2 Docking, Berthing, Deployment, and Payload Integration

The Space Station MRMS is employed to dock to the vehicles when they are in the immediate vicinity of the Space Station, and is used to transport the vehicles and their payloads to storage locations, and to berth them in those locations. The MRMS is used to transport ORUs and fluid tankers about the SS, and to assist in the mating of the vehicles and their payloads. Likewise the MRMS is used to deploy the vehicles and payloads. This requires the capability to control the MRMS and the OMV flight during consecutive portions of the vehicle flight operations.

6.6.1.3.3 Monitoring

All OMV subsystems require monitoring while the vehicles are being operated. In addition, the accommodations subsystems require monitoring during all times. The

subsystems include fluid storage, fluid conditioning, fluid transfer, electronics subsystems, and maintenance subsystems. The monitoring function is automated, with notification of anomalies made to the crew.

6.6.1.3.4 Check-out

OMV and accommodations elements require periodic check-out to ascertain whether they are operating correctly, especially after being serviced.

6.6.1.3.5 Service and Maintenance

The OMV and accommodations require regular service and occasional maintenance. The OVCC accommodates activity scheduling, inventory tracking, procedures control, and contingency plans.

Additional detailed information on OMV accommodations can be found in Boeing Document D483-50022-6, Vol I (DR-02) dated October 31, 1986.

6.6.2 OTV Accommodations

6.6.2.1 Space Station OTV Reference Configuration Data

The current phase of design of the OTV leaves many critical areas still under consideration, most notably the manner of aero-assisted braking to be used with the vehicle. Raked cones, shields and ballutes have substantial geometric differences, as well as differences in their servicing requirements for regular re-use. The variations in possible OTV design concepts and missions also result in changes in the accommodations facilities, from size and shape of hangar to the spares storage facilities and propellant resupply volumes required.

The following OTV Space Station reference configuration description was pro-

vided by NASA on August 30, 1985. This data will be used for initial OTV accommodations analyses. See Figure 6.6.2.1-1.

OTV Envelope:	10972.8mm (432 in) in length
	13411.2mm (528 in) diameter Aerobrake
Propellant	LO 2
	LH 2
RCS	Hydrazine
OTV Weight	31297.7 KS (69,000 lb)

6.6.2.2 OTV Accommodations Reference Configuration Data

The SBOTV at the FOC station will transfer payloads to and from higher energy orbits. The initial spaced based OTV accommodations will be sized to support the OTV Program Phase A, Rev 8A low mission model through the manned GEO missions. Phase A OTV studies indicate one single stage OTV can perform the Rev 8A low mission model up to but not including the lunar missions. The OTV accommodations must grow to allow the support of lunar missions which require a dual stage OTV stack.

The initial SBOTV accommodations will consist of fluid storage, conditioning, and transfer equipment, a maintenance and repair facility, and a Multipurpose Applications Console (MPAC). The MPAC will be located in a pressurized area and will be used to monitor, checkout and control the OTV and its accommodations.

The fluid storage facility will be capable of storing 90,100 kg (200,000 lb) of cryogenic propellants. This storage capacity

will be updated when final Phase A OTV study results are available. The initial OTV accommodations mass on the FOC station is estimated to be 115,700 Kg (254,530 lb). This estimate includes a dry OTV, a tank farm with propellant, ORU's, service and maintenance facility, and ancillary equipment. See Table 6.6.2.2-I, OTV Accommodations Mass Summary. The OTV accommodations mass will increase during the growth period because of the additional OTV stage required for Lunar missions and its storage facility.

It is anticipated that the OTV Space Station Reference Configuration will be affected by the Phase A OTV study. Three Phase A contractors are generating OTV concepts. Currently no Phase A OTV reference configuration exists. The SBOTV IOC is scheduled for 1999 in the Phase A Rev 8A low mission model. Figure 6.6.2.2-1 shows a typical operations scenario.

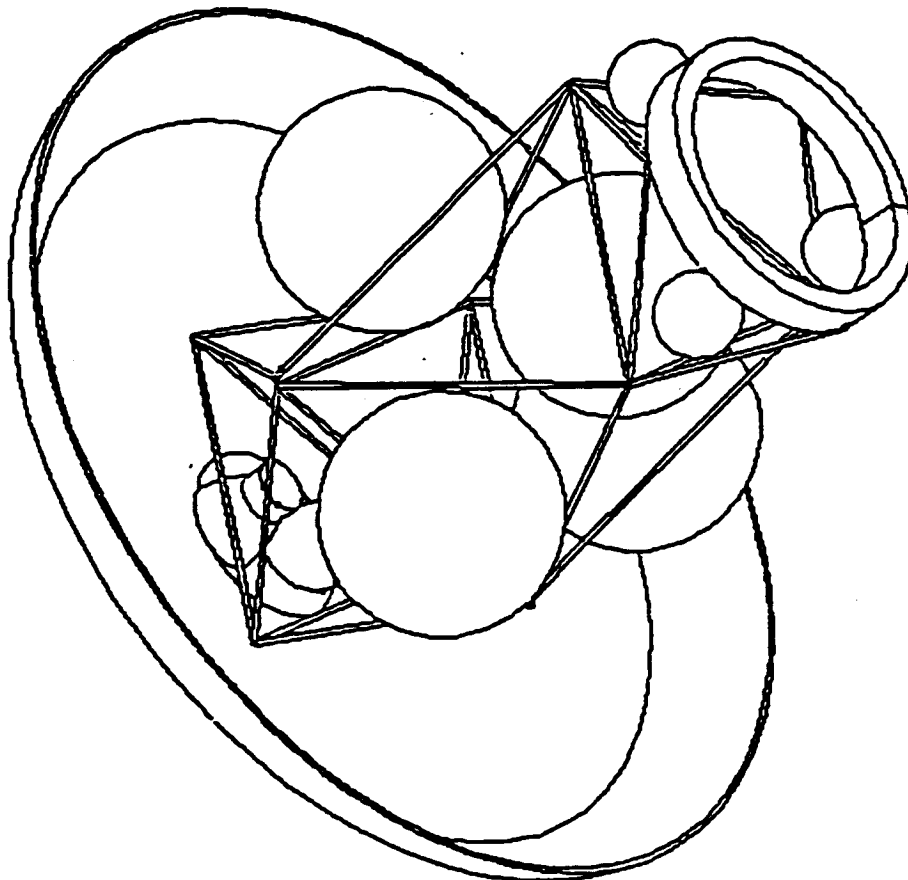
6.6.2.3 OTV Accommodations Growth

The following discussion is based on the Rev 8A, OTV mission model. The model has two levels of flight frequency.

These flight frequencies are designated "low" and "nominal." The low model represents a level of activity which characterizes a level budget and utilization of existing launch facilities and vehicles. The nominal model represents a level of activity which characterizes a slow net gain in NASA budget and the acquisition of facilities, equipment and vehicles to allow a yearly shuttle launch rate growing to approximately 40 flights per year.

Lunar missions identified in the mission models drive on station growth of the OTV Accommodations. Lunar missions first occur in 2006 and 2015 for the nominal and

Vehicle -10972.8mm (432 in)
in Length



13411.2mm (528 in)
Diameter Aerobrake

FIGURE 6.6.2.1-1 OTV SPACE STATION REFERENCE CONFIGURATION

TABLE 6.6.2.2-I OTV ACCOMMODATIONS MASS SUMMARY

TABLE 2.1-I OTV ACCOMMODATIONS MASS SUMMARY

		<u>Mass lbs.</u>
•	Propellant Resupply and Storage	
-	LH 2 Tank System (2)	1555
-	LO 2 Tank System (2)	3480
-	Propellant Transfer Equipment	
-	Propellant Storage System	
-	Translator (2)	1400
-	OTV Resupply Tanker	
		3110
		6960
		1480
		2800
		3770
•	OTV Maintenance and Checkout Facility	
-	OTV Berthing Assembly	
-	Tools and Support Equipment	1200
-	Payload Integration Stand	760
		380
•	OTV Storage Facility	
-	Hangar	
		25,000
•	OTV	
		9,070
•	LO 2	
		171,430
•	LH 2	
		<u>28,570</u>
	TOTAL	254,530 lbs

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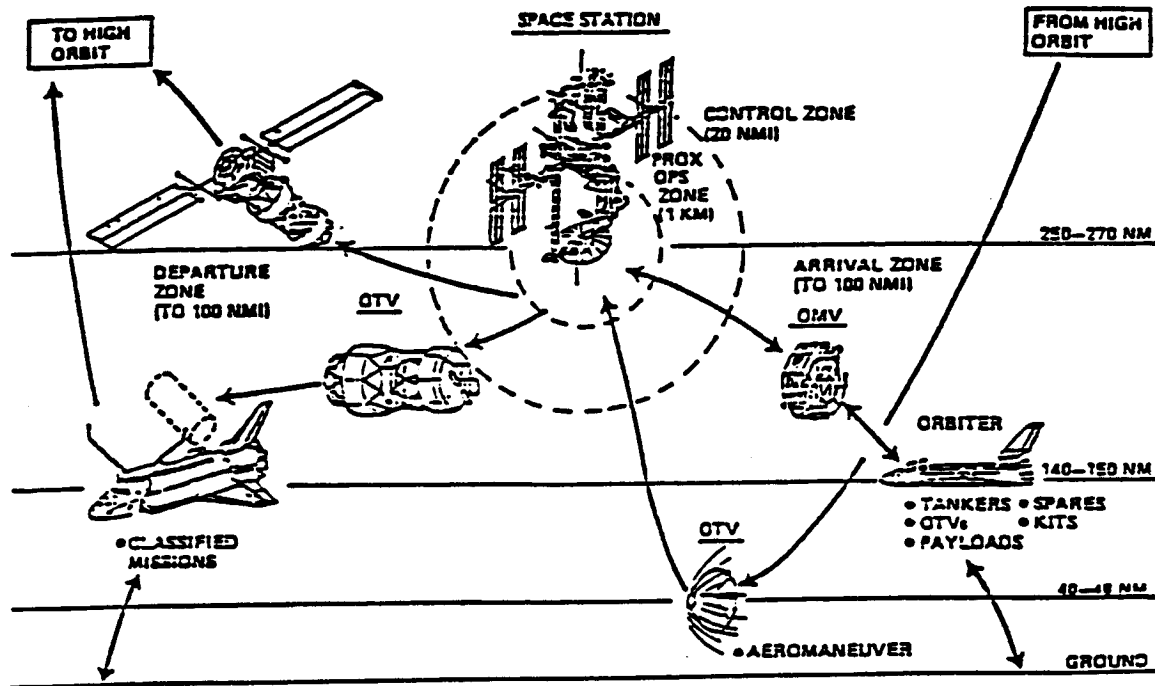


FIGURE 6.6.2.2-1 SPACE STATION OPERATIONS SCENARIOS

low mission models respectively. Figures 6.6.2.3-1 through 6.6.2.3-2 is a summary of mission frequencies for each level.

Enlargement of the original storage and maintenance facility must be completed before the first 80 K lb lunar delivery mission. No 80 K lb lunar missions are scheduled in the low model, however Figure 6.6.2.3-3 indicates a projected time for 80 K lb lunar missions. These projections are beyond the Rev 8A mission model envelope of 2010. Enlarging the existing facility would increase its size to 16.4 x 19.2 x 27.4 meters (54 x 63 x 90 feet).

Additional detailed information on OTV accommodations can be found in Boeing Document D483-50022-6, Vol III (DR02) dated October 31, 1986.

6.6.3 Smart Front End

This section summaries specific design requirements and general design constraints for Smart Front End.

6.6.3.1 Documented Requirements

General SFE performance and interface requirements are provided or referenced in document SS-SPEC-0009 "Contract End Item for Space Station Smart Front End."

6.6.3.2 Derived Requirements

The documented requirements are of a general nature and do not include the specific customer servicing data necessary for preliminary design. This includes ORU designs, manipulation requirements, fluid types and quantities, mission timelines, etc. Therefore, the development of requirements for the SFE and OMV Mission Kits were derived from sources such as the Langley Data Base, BDM report (OSSA Space Station Servicing Data Book), Customer Servicing Requirements

Report JSC 30000 Section 5, STS EVA Description and Design Criteria JSC 10615, Rev A, RUR-2 Platform Requirements input from WP-03 and Space Station Maintenance Requirements from WP-01.

6.6.3.3 Ground Rules

The following ground rules apply to the SFE and OMV Mission Kits:

- a. MCS is able to handle and transfer the SFE and Kits.
- b. Micrometeoroid and debris protection are not required.
- c. SFE and Mission Kits are based at the Space Station.
- d. The Space Shuttle will resupply the Space Station at 90 day intervals.
- e. The reference configuration (dual keel) of the Space Station will be used.
- f. The MSFE reference design of the OMV will be used.
- g. ORU and fluid resupply from ground to orbit is not a SFE responsibility.

6.6.3.4 General Description

The SFE is a modular system consisting of a telerobotic system, ORU carrier, fluid resupply system and tools. Additional module kits such as power and communication kits will be added if deemed necessary. At this time the reference OMV, or MSC can handle the interface requirements on Table 6.6.3.4-I. A drawing tree is shown in Figure 6.6.3.4-1. Table 6.6.3.4-II and Figure 6.6.3.4-2 provides list of SFE elements and depicts the SFE configuration respectively.

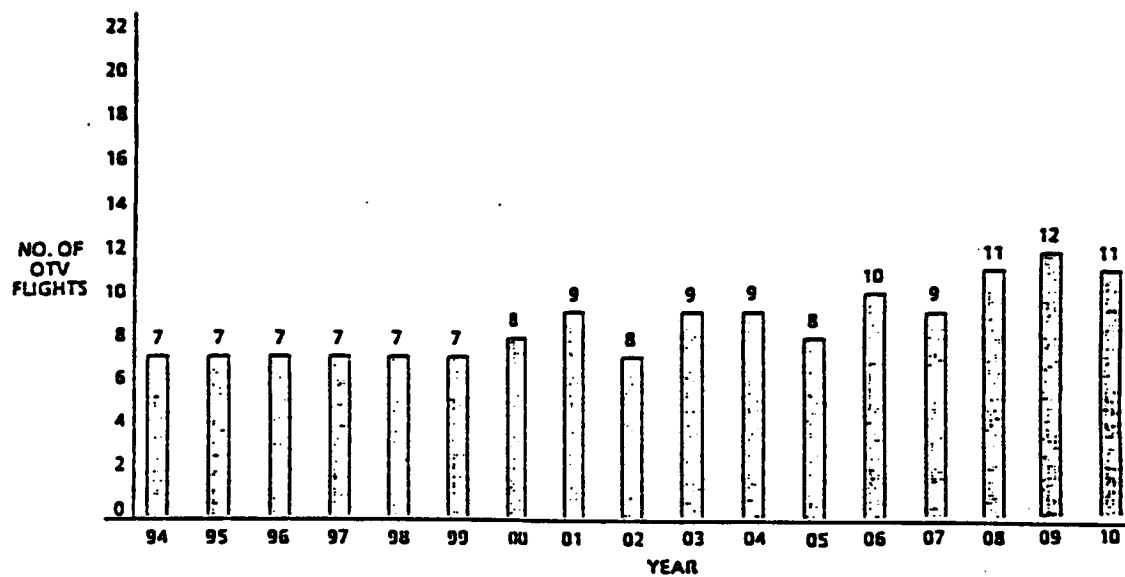


FIGURE 6.6.2.3-1 MISSION MODEL FLIGHT FREQUENCY (LOW MODULE)

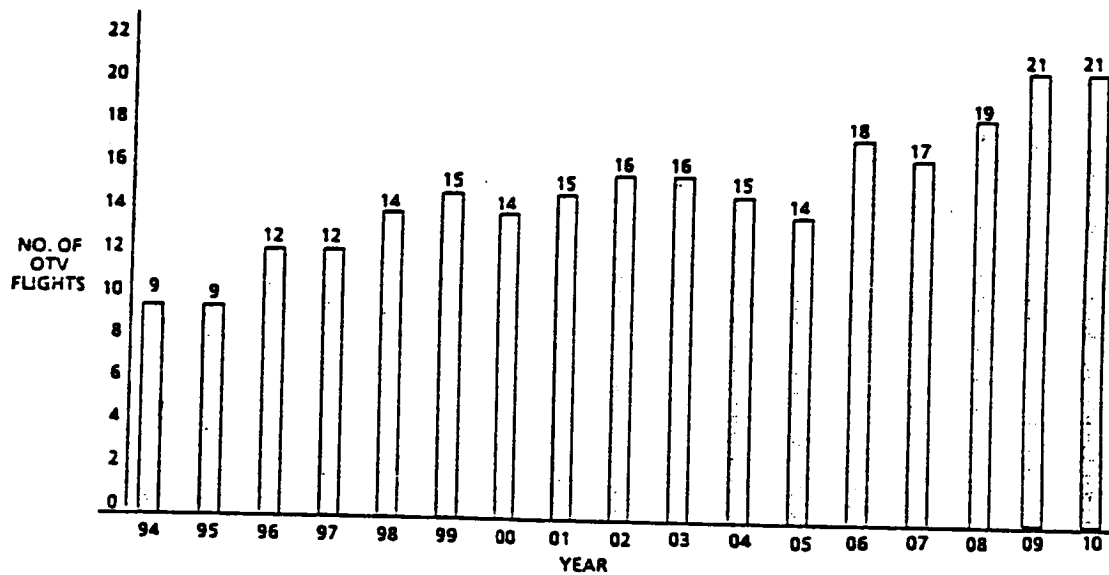


FIGURE 6.6.2.3-2 MISSION MODEL FLIGHT FREQUENCY (NOMINAL MODEL)

PAYLOAD NO. SERIES	MISSION GROUP	WEIGHT (LB) UP/DOWN	LENGTH (FT)	MISSION MODEL		IOC (YEAR)
				LOW	NCM	
13000	EXPERIMENTAL GEO PLATFORM	12000/0	30	1	1	2000/1995
13000	OPERATIONAL GEO PLATFORM	2000/0	35	5	6	2004/1993
13000	UNMANNED PLAT. SERVICING	7000/4500	9	1	1	2001/1995
15000	MANNED GEO SORT	7500/7500	10	3	17	2008/2002
15000	GEO SERVICE STATION ELEMENTS	13000/0	15-20	2	2	2002/1998
15000	GEO SERVICE STA. LOGISTICS	12000/2000	15	5	26	2004/1998
17000	PLANETARY	2000-4000/0	5-35	6	14	1994/1994
17000	UNMANED LUNAR	5000-20000/0	20	2	2	2007/2001
17000	MANNED LUNAR SORT	80000/15000	50	0	3	2015/2006
17000	LUNAR BASE ELEMENTS	80000/0	53	0	3	2020/2008
17000	LUNAR BASE SORT/LOGISTICS	80000/10000	60	0	6	2021/2009
18000	MULTIPLE GEO PAYLOAD DELIVERY	12000/2000	25	46	79	1994/1994
18000	LARGE GEO SATELLITE DELIVERY	20000/0	20-35	3	7	2001/1997
19000	DOD (GENERIC)	12000-20000 (EQUIV)		48	85	1959/1994
			SUBTOTALS	142	252	
10100	REFLIGHTS			3	5	1996/1997
			TOTALS	145	257	

FIGURE 6.6.2.3-3 OTV MISSION MODEL COMPOSITION SUMMARY

TABLE 6.6.3.4-I SFE INTERFACE REQUIREMENTS

Accommodations Interfaces (3,000 lb, 1 truss bay)

Physical	includes fluids & ORUs
Mechanical	4 truss nodes 1 automatic electric umbilical
Electrical	50-100 watts
Data	Negligible
Fluids	None

Operation Interfaces (with OMV, SS MSC)

Physical	6500 lbs, 14 x 14 x 7 ft (includes fluids & ORUs)
Mechanical	2 active and 1 passive trunnion/keel pin latches (to SS) 2 RMS grapple fittings with electrical umbilical (to OMV & MCS) electrical umbilical (to SS)
Electrical	1420 watts (peak)
Data	3-Mpbs video signal (2 color cameras) 1-2 Kpds command data rate 2 Kpds return data rate
Fluids	None

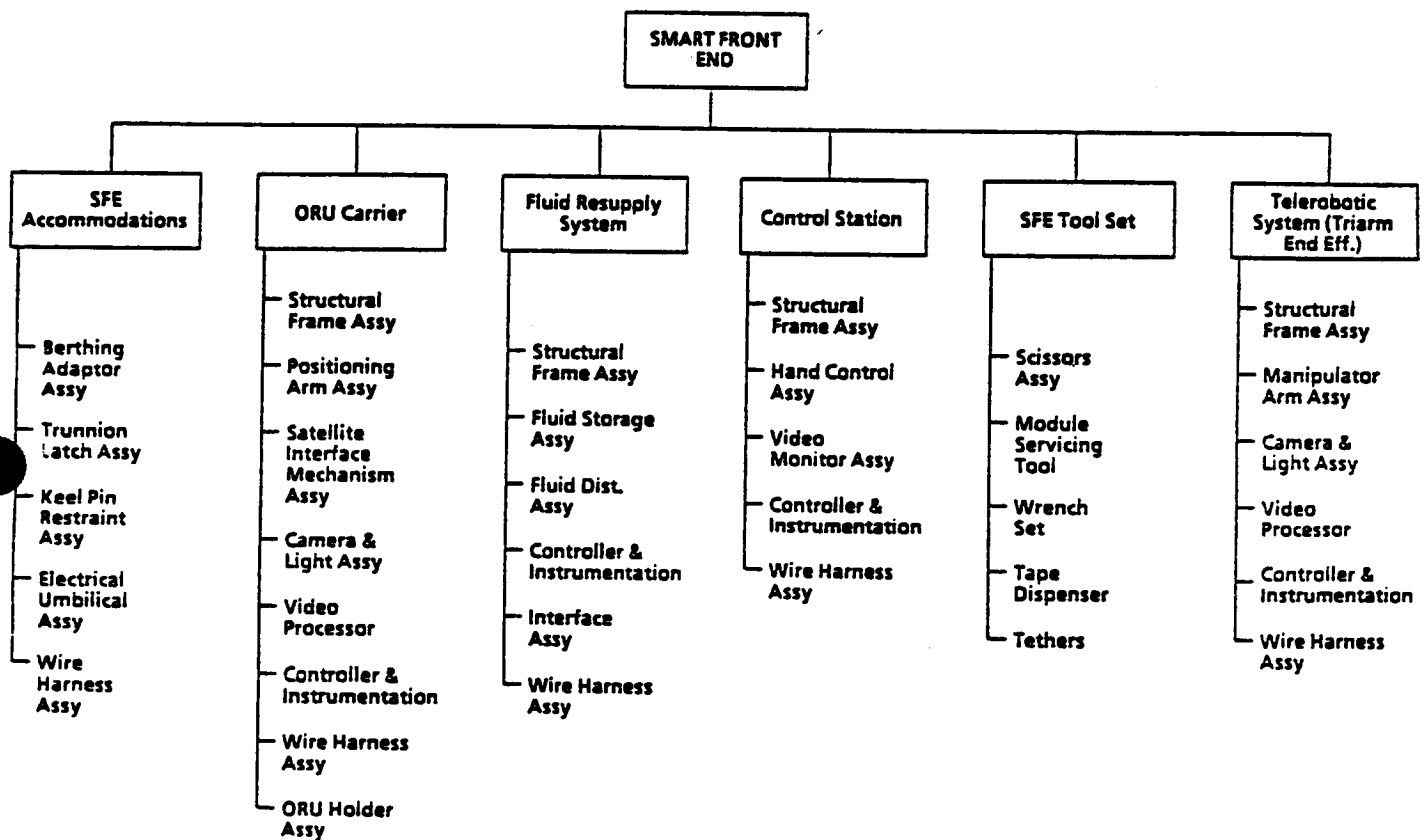


FIGURE 6.6.3.4-1 SFE DRAWING TREE

TABLE 6.6.3.4-II SMART FRONT END ELEMENTS

ITEM	QUANTITY
*Telerobotic System	-
Structural Frame	1
Manipulator Arm Assy	3
Camera	2
Lights	2
End Effector	3
Wire Harness Assy	1
Camera Control & Video Processing	1
Controller	1
Grapple Fitting (with elec. interface)	1
Interface Assy	1
Control Station	TBD
SFE Tool Set	-
Scissors	1
Tape Dispenser	1
MST Tool	1
Wrench Set	1
SFE Accommodations	-
Berthing Fixture	1
Wire Harness	1
Interface Assy	1
ORU Carrier	-
Structural Frame	1
Positioning/Manipulator Arm	1
Camera	TBD
Lights	TBD
Wire Harness Assy	1
Camera Control & Video Processing	1
Hydrazine Refueler	-
Structural Frame	1
Fluid Storage Assy	1
Fluid Dist. Assy	1
Instrumentation & Control Assy	1
Interface Assy	1

TABLE 6.6.3.4-II SMART FRONT END ELEMENTS (Cont'd)

Software

ITEM	QUANTITY
Arm Control Analyzer (positioning arm)	
Arm Control Analyzer (positioning arm)	
Video Signal Handler	
Health Monitoring Handler	
Proximity Sensing Handler	
End Effector Analyzer	

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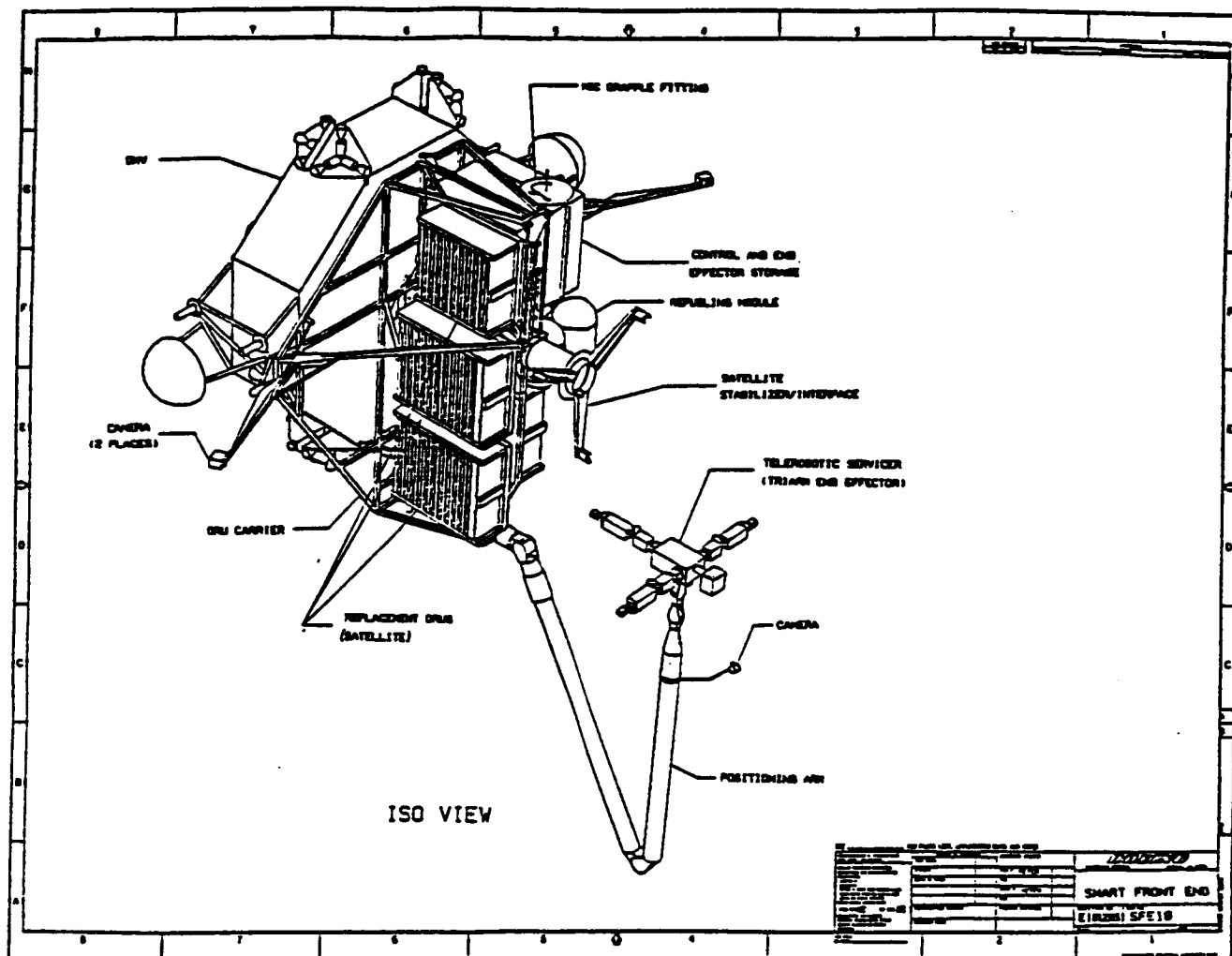


FIGURE 6.6.3.4-2 SMART FRONT END

6.6.3.4.1 Telerobotic System

The telerobotic system is a humanoid type manipulator consisting of at least a body like base, three manipulator arms, a head camera, grapple fittings, wire harness and electronics.

The base is approximately 203.2 x 304.8 x 457.2 mm (8 x 12 x 18 in). It will be made out of aluminum or graphite epoxy. A grapple fitting is fitted to the back of the base. The grapple fitting has an electrical receptacle for operating on the MSC positioning arms. An interface utilizing the grapple fitting electric receptacle will also be designed for mounting on the ORU carrier positioning arm. The manipulator arms are 660.4 mm (26 in) long. They incorporate end effectors, controls, motor modules, joints and heaters. A camera may be mounted on the wrist of each arm. A head camera may also be used. It is mounted on a 152.3mm (6 in) "neck" and the base of the neck has pan and tilt capabilities. The electronics consist of a data processor. A video processor may also be used.

The telerobotic system is used as an end effector for either the ORU carrier positioning arm or the MSC arm.

6.6.3.4.2 ORU Carrier

The ORU carrier consists of a structural frame, positioning arm, cameras, satellite interface, OMV interface, payload interfaces and electronics. Figure 6.6.3.4.2-1 through 6.6.3.4.2-6 describe these components.

6.6.3.5 Interfaces With Other Elements.

The following describes the various elements the SFE interfaces with, the possible interfaces, and the interfaces chosen for the SFE.

With OMV:

The SFE may use any of the three structural interfaces with the OMV: the grapple,

the FSS latches or the trunnions and keel pin. The grapple and the FSS also have electrical umbilicals associated with them that the SFE may use. A unique electrical umbilical may be required if the trunnions and keel pin are used (a front mounted SFE could use the grapple in conjunction with the trunnions and keel pin). The Boeing Phase B SFE concept uses the grapple fixture.

The current grapple can handle up to 1200 ft-lb torque. The reference MSFC OMV can input a torque upto 1750 ft-lb. This discrepancy may be corrected as better OMV definition is available. As a last resort, the interface may be changed. It is notable that this problem is not unique to the SFE, satellites that use the grapple to interface with the OMV will also have this concern.

With Satellite:

Six possible ways to interface with satellites have been identified:

- grapple fitting used by OMV
- grapple fittings other than above
- FSS pins used by OMV
- trunnions and keel pins
- EVA handholds
- EVA foot restraint sockets

Of the above interfaces, only the grapple fitting and FSS pins used by the OMV have associated electrical connections; also, these interfaces must be used when reboosting the satellite. The Boeing Phase B SFE concept uses these interfaces for

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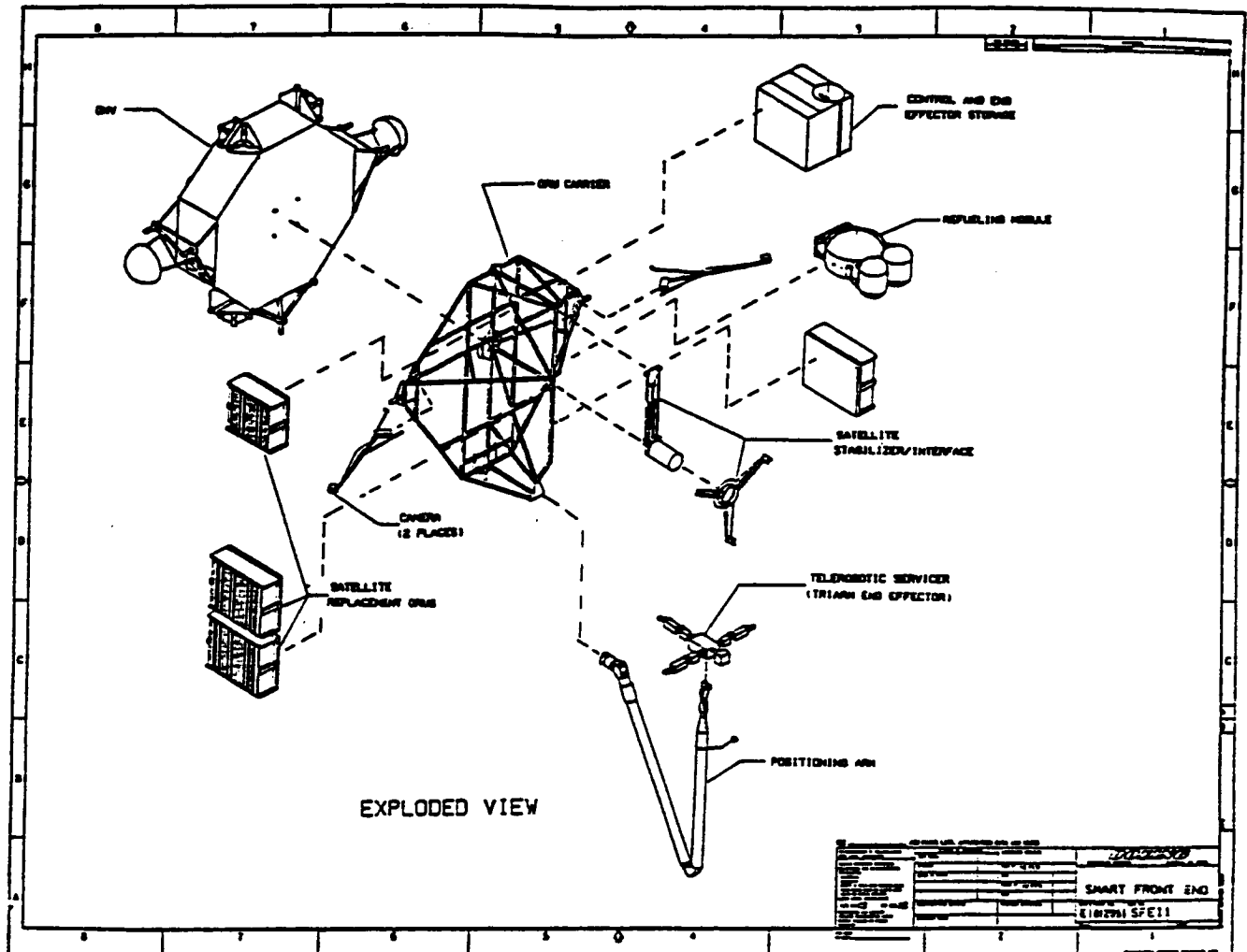


FIGURE 6.6.3.4.2-1 SMART FRONT END, EXPLODED VIEW

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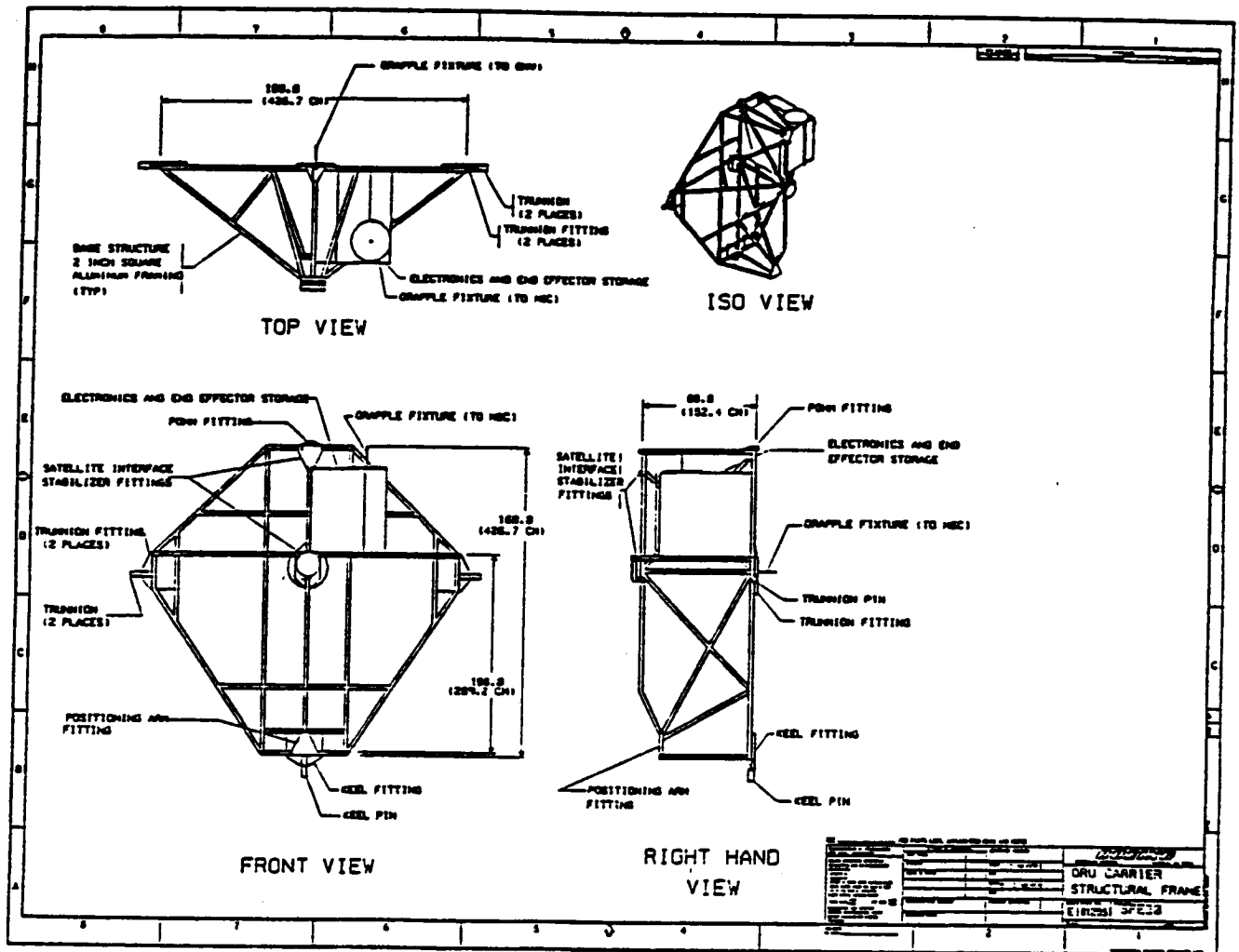


FIGURE 6.6.3.4.2-2 ORU CARRIER, STRUCTURAL FRAME

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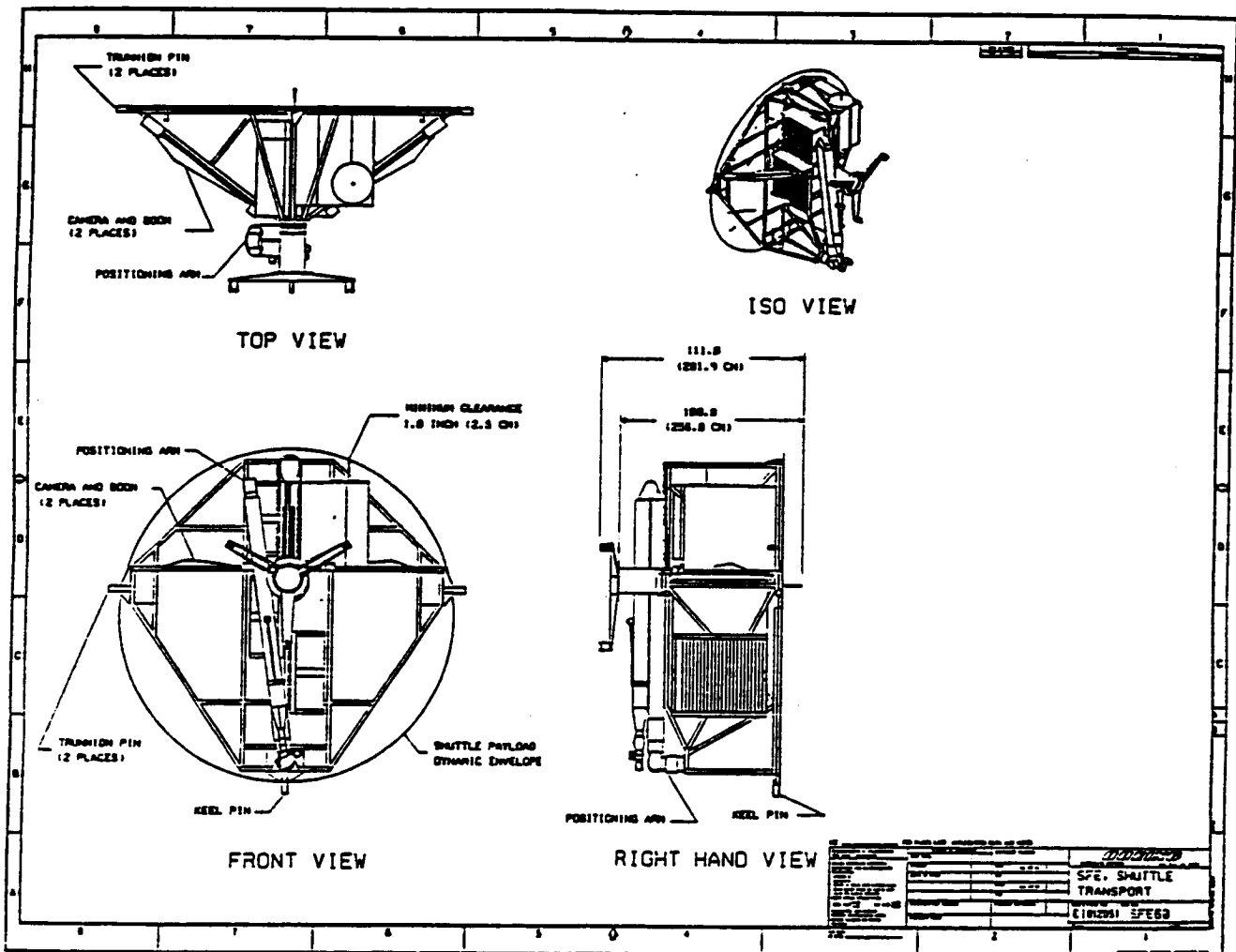


FIGURE 6.6.3.4.2-3 SMART FRONT END, SHUTTLE TRANSPORT

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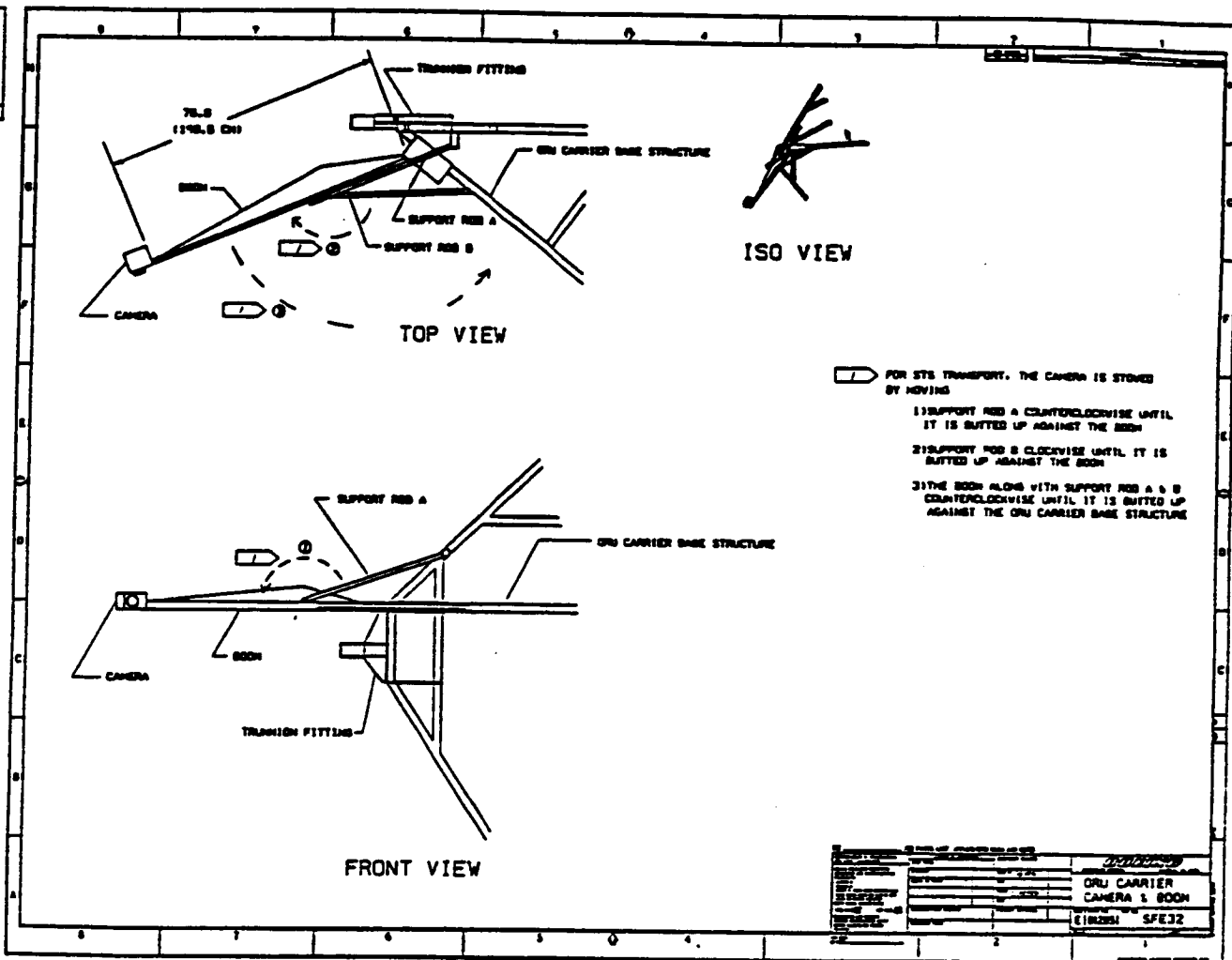


FIGURE 6.6.3.4.2-4 ORU CARRIER, CAMERA AND BOOM

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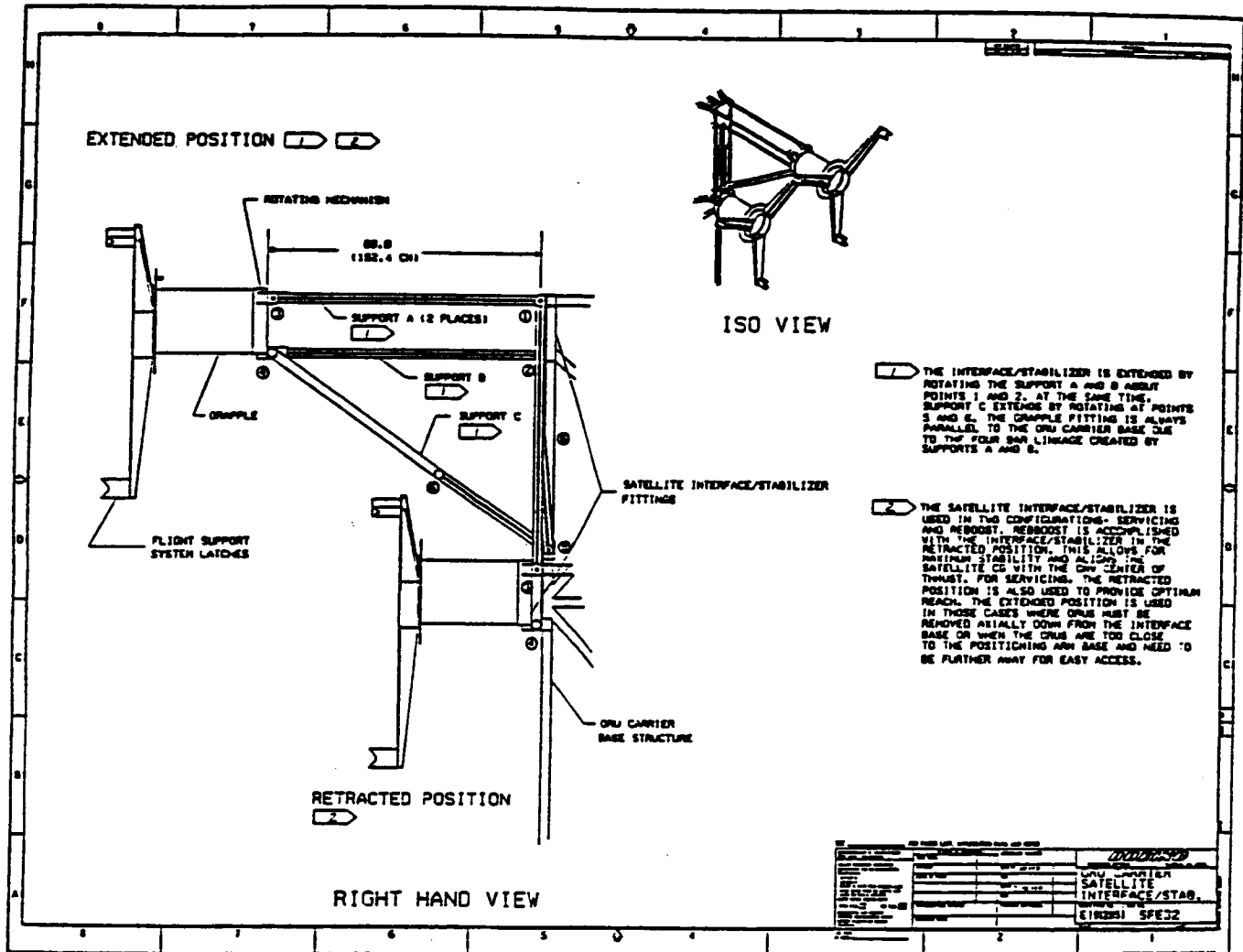


FIGURE 6.6.3.4.2-5 ORU CARRIER, SATELLITE INTERFACES/STABLIZER

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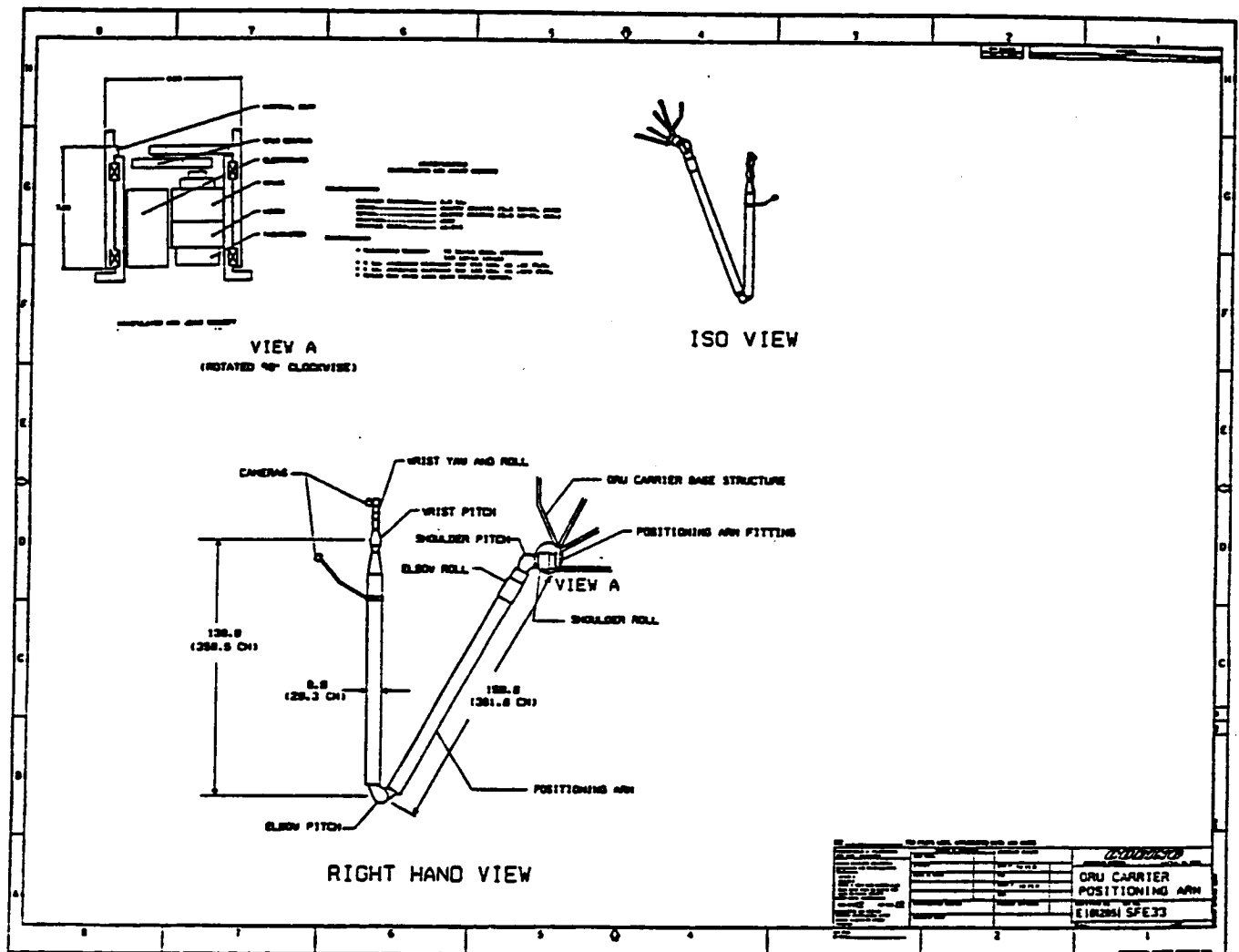


FIGURE 6.6.3.4.2-6 ORU CARRIER, POSTIONING ARM

hard docking. The other interfaces may be used by the telerobotic system for stability.

With Satellite ORU's (Positioning Arm/Telerobotic System):

ORU interfaces currently consist of:

- EVA handholds
- 7/16" bolt heads
- (TBD) appendage drive heads
- MMS attachment
- EVA wing tab electrical connectors
- latch handles
- switches
- RMS grapple fitting
- other interfaces in current development for platforms
- Through the use of grippers and various end effectors, the SFE will interface all the above ORU interfaces.

With Satellite ORUs (ORU Carrier):

- The mounting scheme between the ORU carrier and the satellite ORUs has not been defined. If possible, it will be common with the exterior logistics carrier.

With Space Station:

- SFE Accommodations interface with the truss node, the Space Station power system, DMS system and communications system. Physical characteristics are not yet known.

- The SFE control station is part of the MPAC.
- The SFE shall have a grapple fitting with electrical connectors for interfacing with the MSC.

With Ground:

- An SFE ground control station shall interface with the OMV ground control station.

6.6.3.6 Operation Scenario

The purpose of the Smart Front End (SFE) is to reduce OMV propellant and EVA costs. The module system can handle the total servicing requirements of most satellites reviewed.

This system operates in three modes as follows: 1) attached to the OMV, 2) attached to the MSC, and 3) attached to the SFE Space Station Accommodations.

6.6.3.6.1 Telerobotics System Attached to the MSC

The MSC positioning arm attaches to the grapple fitting located on the back of the telerobotic system (TRS). The positioning arm provides power, communications and data to the telerobotic system via the grapple electrical connector. The telerobotic system releases from its berthing fixture on either the ORU carrier or accommodations. The MSC transfers the TRS to the SS maintenance ORU storage area. The TRS picks out the replacement part and attaches it to the MSC base. The MSC transfers the TRS to the servicing location. The TRS attaches one or two manipulator arms to the serviced element structure for stability and removes the replaced part. The part is transferred to the MSC base

and the replacement part is picked up. The replacement part is installed. The procedure is then reversed. If the ORU can be replaced with only one TRS arm, the ORU may not have to be stowed on the MSC base.

6.6.3.6.2 SFE Attached to the OMV

A SFE operation is described for the SFE replacing a satellite multi-mission modular spacecraft (MMS) module and electronic box.

It is determined that two ORU's need replacement on a satellite. New ORU's are mounted on the logistics pallet and flown to the Space Station. The pallet is removed from the Shuttle and transferred to the SFE.

The ORU's are mounted on racks that interface with the pallet and the ORU carrier. If necessary, the rack has a box for protecting the ORU's. The ORU rack is transferred by the SFE positioning arm from the pallet to the ORU carrier. If necessary, an electrical umbilical is mated to the rack. The MSC then grabs the SFE. The SFE fixture latches are opened, the MSC transfers the SFE to the OMV. The SFE and OMV are mated. Still holding to the SFE, the MSC transfers the SFE-OMV to a release point. The OMV flies the SFE to the satellite. The SFE docks to the satellite. If needed, power is supplied from the SFE to the satellite. The SFE positioning arm attaches to a module servicing tool (MST). The arm then detaches the replaced MMS module from the satellite and places it in a temporary fixture on the ORU carrier. Leaving the MST in the replaced MMS module, the arm end effector opens the cover of the rack box (if necessary). The end effector then reattaches to the MST and the arm removes the replacement MMS module from its box and installs it on the satellite. The arm installs

the replaced MMS module in the box and closes the box.

The replacement of the second ORU is a detailed task requiring the telerobotic system. The replacement involves such jobs as cutting and taping MLI, installing hinge pins, removing bolts and removing EVA wing tab type electrical connectors.

The positioning arm attaches to the TRS. The TRS grabs a tool (such as a scissors), and the positioning arm transfers the TRS to the satellite ORU. The TRS performs detailed work, changing tools as required. When the ORU is changed out, the TRS is stored, the positioning arm restrained, and the OMV flies the SFE back to the Space Station.

It is anticipated that at least 50% of satellite servicing can be accomplished by the positioning arm without the TRS. To reduce actuators, the positioning arm will also deploy the camera booms and actuate the satellite interface/stabilizer mechanism. Figure 6.6.3.6.2-1 shows the SFE servicing SPARTAN.

6.6.3.7 SFE Accommodations

The Space Station SFE accommodations consist of a berthing adaptor that supports the SFE and hydrazine resupply modules. The SFE is mounted in such a way to provide easy positioning arm access to the MSC (for self loading) and easy MSC and EVA access to the SFE. The hydrazine modules are located to allow self loading by the positioning arm (if allowed) and loading by the MSC. The accommodations adaptor is attached to the Space Station in close proximity to the OMV to limit MSC travel during stackup. Optimally, the adaptor will also be close to the external ORU storage area and S.S. hydrazine resupply area to limit MSC travel when loading the SFE.

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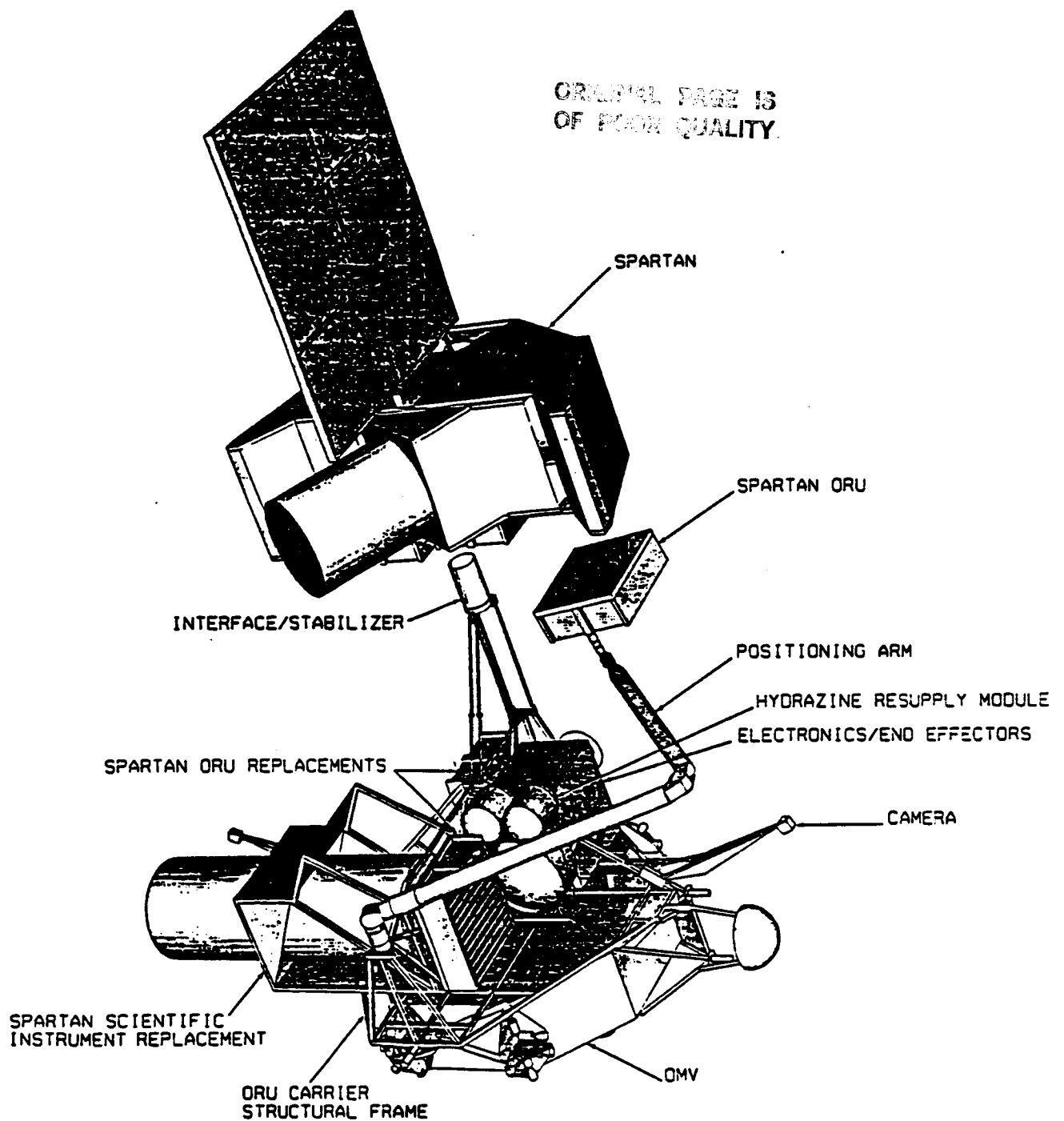


FIGURE 6.6.3.6.2-1 SFE SERVICING SPARTAN

SFE accommodations also include control station both at the Space Station and on ground. The Space Station Control Station is MPAC. A ground station that interfaces with the OMV control transmission and reception will be provided for situ servicing (a ground based activity).

Detailed information on SFE can be found in Boeing Document D483-50022-6, Vol II, Rev C (DR-02) dated October 31, 1986.

6.7 Propulsion System

The reference propulsion subsystem concept selected for the Space Station is bipropellant gaseous oxygen and hydrogen from water electrolysis. This system represents state-of-the art design, low-to-moderate initial cost, high performance and low life-cycle cost. This concept is described herein for the baseline configuration IOC Space Station.

Propulsion subsystem impulse requirements for the Space Station dual-keel configuration were provided by the Reboost working group. During the course of these comparative studies, propulsion requirements were defined to provide altitude maintenance through reboost, backup attitude control, collision avoidance, infrequent desaturation of control moment gyros, and damping and stabilization of the station during docking procedures. Growth station impacts were considered and determined not to have a significant impact on the design of the propulsion system.

Other propulsion concepts or combined concepts may be more beneficial to the overall Space Station program by offering reduced resupply costs, integration with other subsystems, the ability to efficiently dispose of unneeded consumables, the enabling of more efficient strategies for formation flying with platforms, reduced

contamination, and/or reduced overall life-cycle costs. Representative of such subsystems are different versions of gaseous oxygen/hydrogen, gaseous neon, gaseous nitrogen, waste gases and low-thrust resistojets.

6.7.1 Propulsion Subsystem Requirements

The propulsion subsystem is required to perform the altitude maintenance and attitude control maneuvers. However, for the reference configuration, the CMGs and magnetic torquers are assumed to be the primary control effectors for performing the attitude control function. Therefore, the propulsion requirements were assumed to fall into two major categories: 1) those that can be done only by the propulsion subsystem and 2) those in which the propulsion subsystem operates in the event that another subsystem fails and a backup capability is required. The primary requirements are:

- a. Reboost and orbit adjustment
- b. Collision avoidance
- c. Accommodation of disturbances resulting from docking, berthing, and movement of objects by the manipulator
- d. Maintenance of an adequate propellant reserve margin.

The backup requirements are:

- e. Three-axis stabilization in the event of failure of momentum exchange devices (in this event, control is provided at a reduced level)
- f. Desaturation of the momentum exchange devices.

6.7.1.1 Guidance, Navigation and Control Requirements

The GN&C requirements and strategy dictate the propulsion subsystem design and operation. The input for the GN&C comes from the operational requirements and the payload accommodation needs. Requirements applicable to propulsion are:

- a. All credible failures of critical system shall have fail operational/fail safe/ restorable levels of redundancy except for pressure vessels
- b. Selective or total inhibits shall be available for EVA operations
- c. Propellant usage data base shall be provided.

6.7.1.2 Requirements

6.7.1.2.1 Operational Requirements

The operational requirements pertain to restrictions and needs based on the overall Space Station. Those requirements pertinent to propulsion are:

- a. The Space Station shall not perform any maneuvers during docking/berthing operations
- b. Maintenance operations including resupply shall consider EVA a limited resource
- c. Maintenance operations shall minimize the need for special skills such as soldering and welding or time consuming procedures
- d. Removal, repair, or replacement of equipment shall be at the ORU level without the need for special fixtures

- e. Subsystems shall be as functionally independent as possible to facilitate maintenance
- f. Subsystems shall be automated to the fullest extent possible
- g. The program shall support the rapid assimilation of new technology without requiring major redesign or revalidation
- h. The station will be resupplied by the Orbiter on a 45, 60 or 90-day basis.

6.7.1.2.2 Customer Accommodation Requirements

One critical customer accommodation requirement that impacts the propulsion subsystem is, that the steady state gravity level of the station shall be designed for 0.3 micro g's or less.

6.7.1.2.3 System Requirements

Requirements placed on all subsystems are:

- a. SSPEs shall have the ability to remain operational indefinitely through periodic maintenance.
- b. Onboard spares shall be provided
- c. Maintenance of ORUs shall not introduce hazardous conditions
- d. Contaminants from external sources shall be limited.

6.7.1.2.4 Safety Requirements

Safety requirements that have a particular impact on the propulsion subsystem are:

- a. Materials in the habitable volumes shall not outgas toxic constituents
- b. Toxic fluid storage or lines shall be external to the pressurized volumes.

6.7.2 Propulsion Subsystem Baseline Configuration Description

The propulsion subsystem consists of four propulsion modules containing thruster clusters and multiple accumulator tanks, one propellant production subsystem containing water electrolysis units and dryers, and one centralized storage facility (consisting of two propulsion modules and a propellant distribution system). A schematic of the propulsion subsystem is shown in Figures 6.7.2-1A - 6.7.2-1E. The propellant production system generates oxygen and hydrogen gas via a static-feed water electrolysis unit. Water from the shuttle, ECLSS, or MTL is electrolyzed using a bootstrapping technique. After electrolysis, the "wet" gases are dried through molecular sieve dryers, which absorb moisture left in the gases after electrolysis. These gases are then distributed out to the four propulsion modules and central storage facility and stored in high-pressure accumulator tanks. The tanks are filled on a continuous basis.

Impulse requirements used to size the propulsion system and determine the average resupply requirements are shown in Figure 6.7.2-2. A 2-sigma atmosphere was used for sizing the accumulator tanks and water electrolysis units, while a nominal atmosphere was used to determine resupply requirements on a 90-day basis. In addition to the 2-Sigma impulse requirement, a 15% contingency was added to include backup attitude control, docking distur-

bances, CMG desaturation, collision avoidance and reserves. Accumulators were sized assuming a 30-day reboost strategy. The four thruster clusters are located in a pattern that accommodates the

varying location of the Space Station center of gravity. Thruster cluster locations are shown in Figure 6.7.2-3. Thruster firing directions provide torques about the X and Y axes of the Space Station and translational capability along the X-axis.

Other significant system features and characteristics:

Peak power includes electrolysis and valve actuation during thruster firings. Average power requirements include electrolysis on a continuous basis only.

Propellant Production Facilities

Two static-feed water electrolysis units are dedicated to the propulsion system. Only one unit is required to operate at a time. The water electrolysis system (WES) uses excess water from either the Shuttle, ECLSS, MTL or some combination. A "bootstrapping" method is used to pressurize the incoming water up to 1,000 or 3,000 psia. This method utilizes high-pressure oxygen, generated from the ECLSS water electrolysis unit, to pressurize water which is drawn into a small accumulator tank. After the water is pressurized from 1 atm to 1,000 or 3,000 psia, it is expelled into the water electrolysis unit. After this has been completed, the accumulator tank is regulated back down to 1 atm and the oxygen is dumped into the atmosphere of the modules. The electrolysis process requires 2.227 kw-hrs/lbm of H₂O electrolyzed, or an average of 1.3 kw of power.

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● System overview

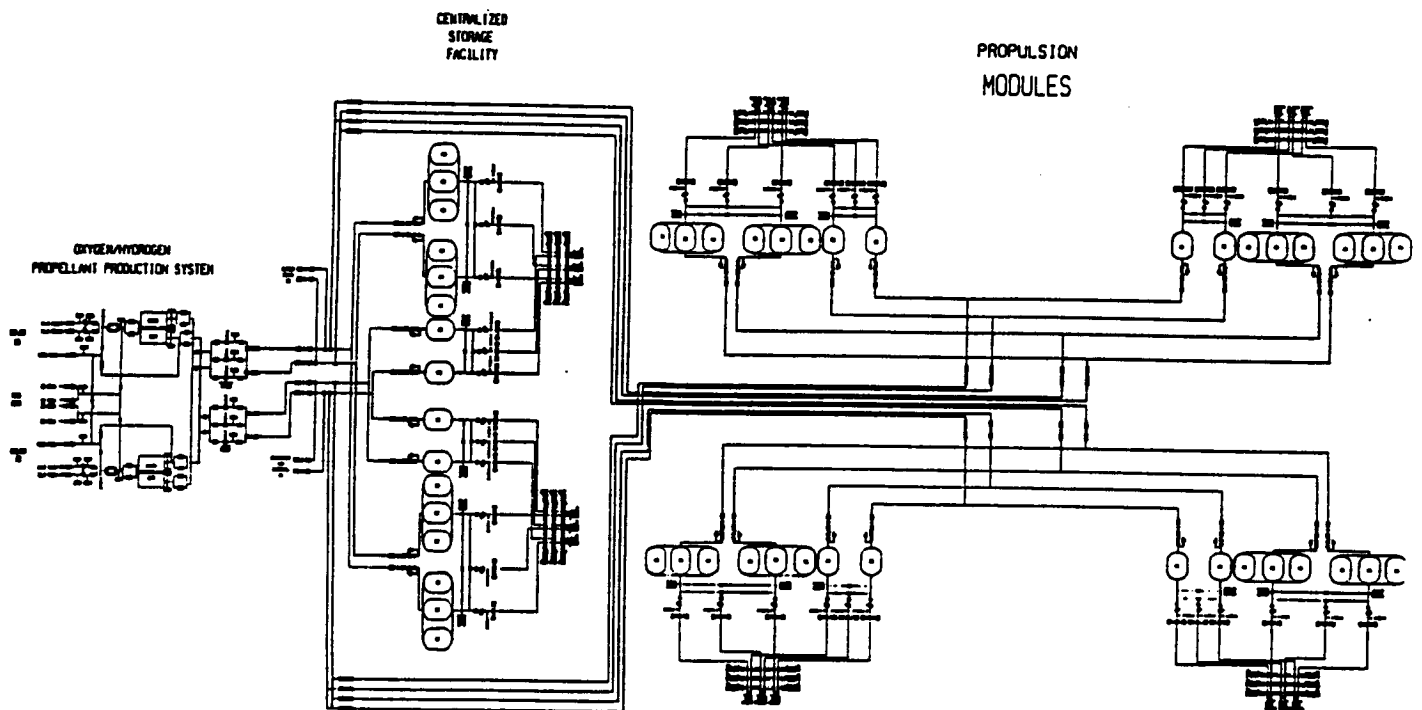


FIGURE 6.7.2-1A O₂/H₂ CONNECTED MODULAR PROPULSION SYSTEM
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● Propellant production facility

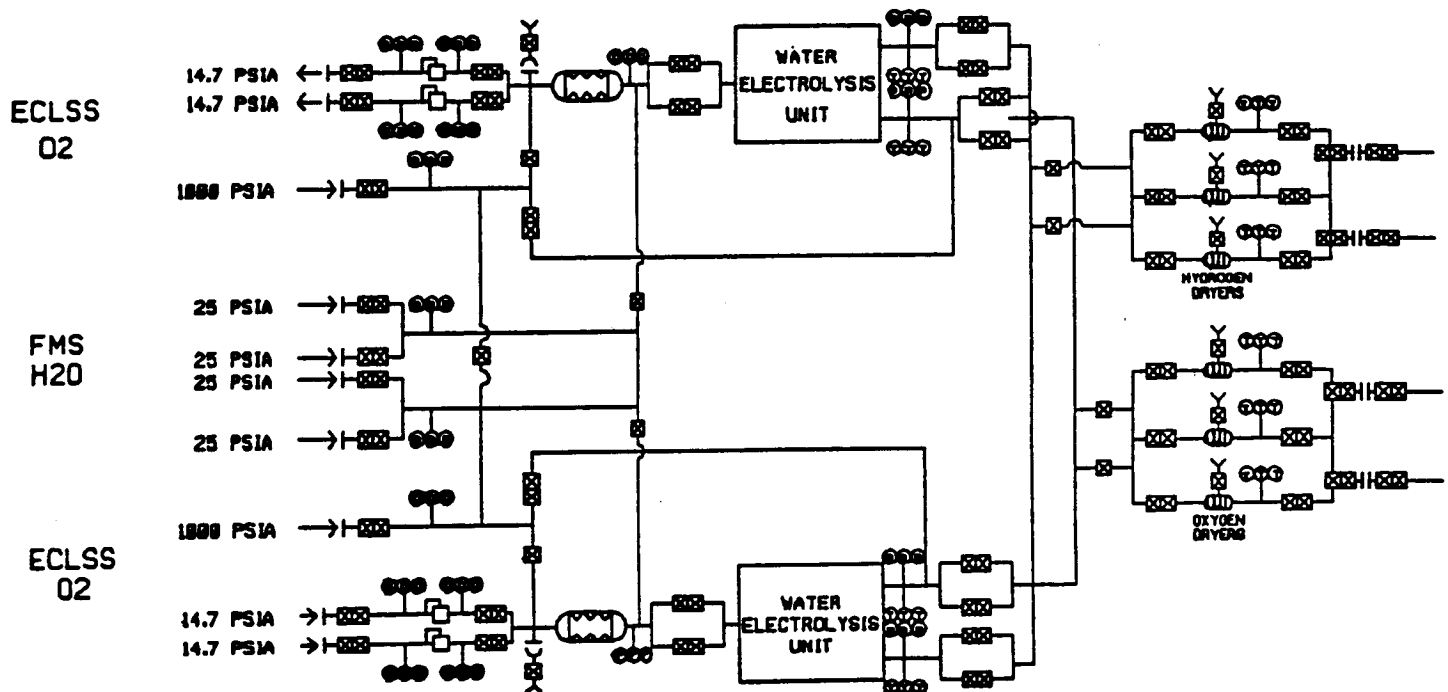


FIGURE 6.7.2-1B O₂/H₂ CONNECTED MODULAR PROPULSION SYSTEM
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● Centralized storage facility

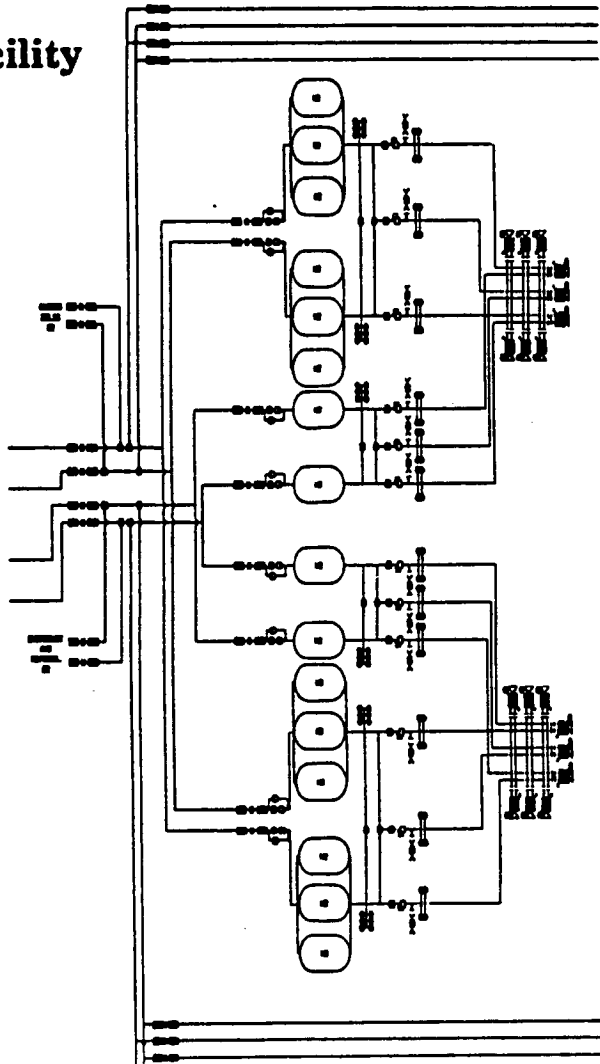


FIGURE 6.7.2-1C O₂/H₂ CONNECTED MODULAR PROPULSION SYSTEM
SCHEMATIC

● Propulsion module

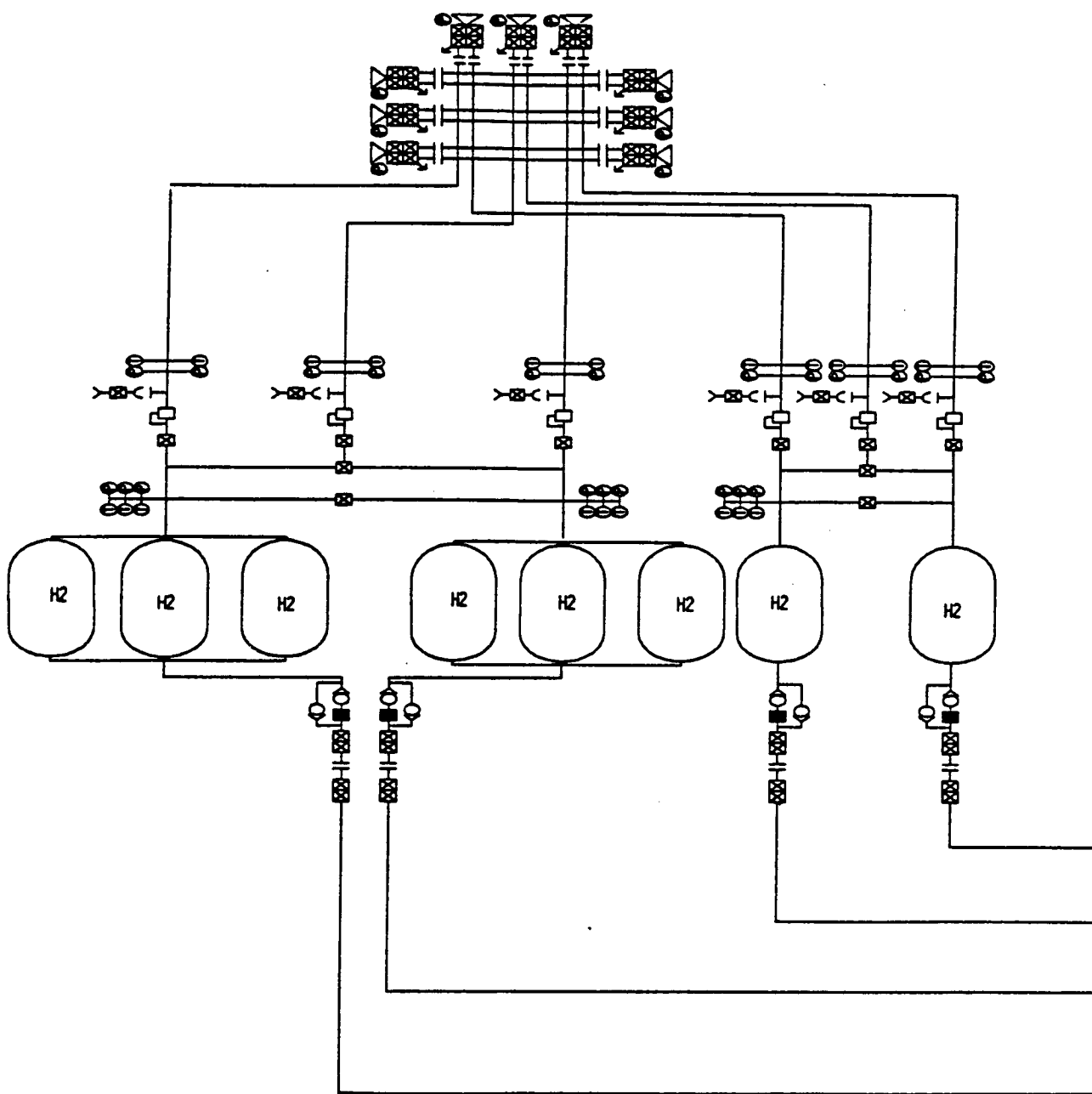


FIGURE 6.7.2-1D O₂/H₂ CONNECTED MODULAR PROPULSION SYSTEM SCHEMATIC

- **Propellant distribution system**

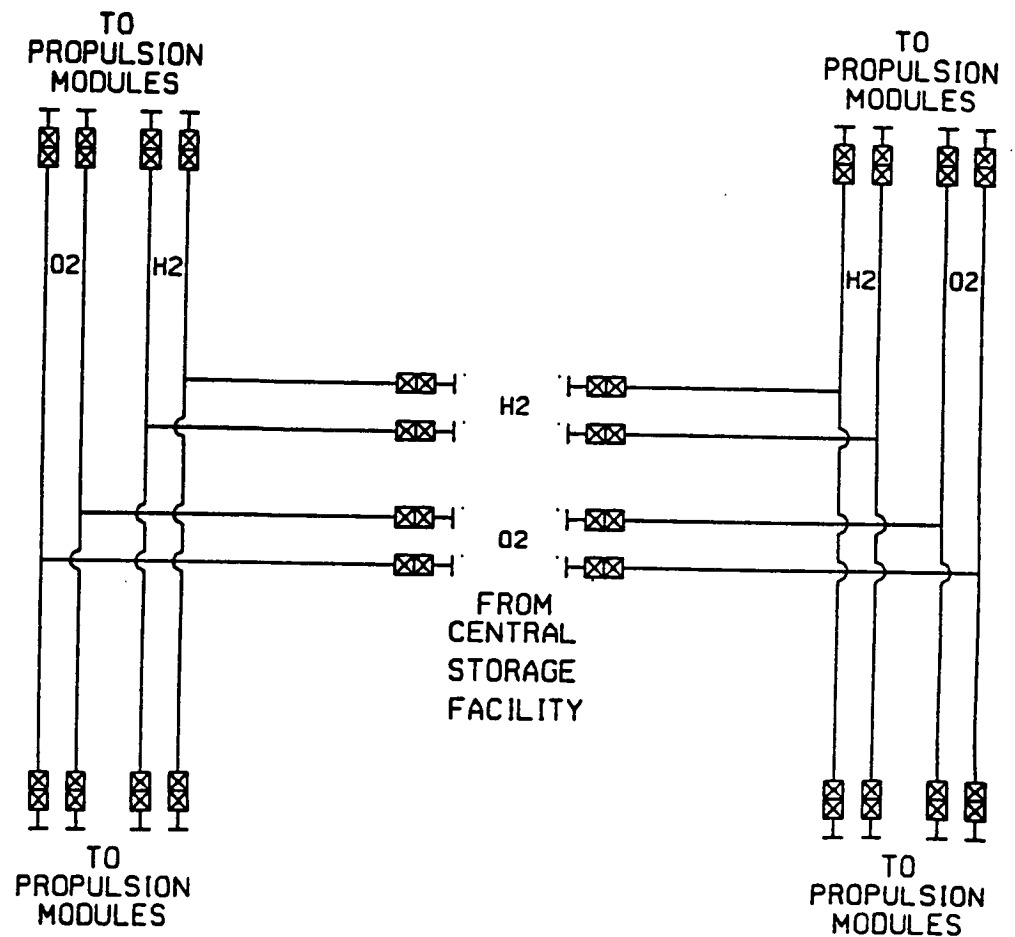


FIGURE 6.7.2-1E O_2/H_2 CONNECTED MODULAR PROPULSION SYSTEM SCHEMATIC

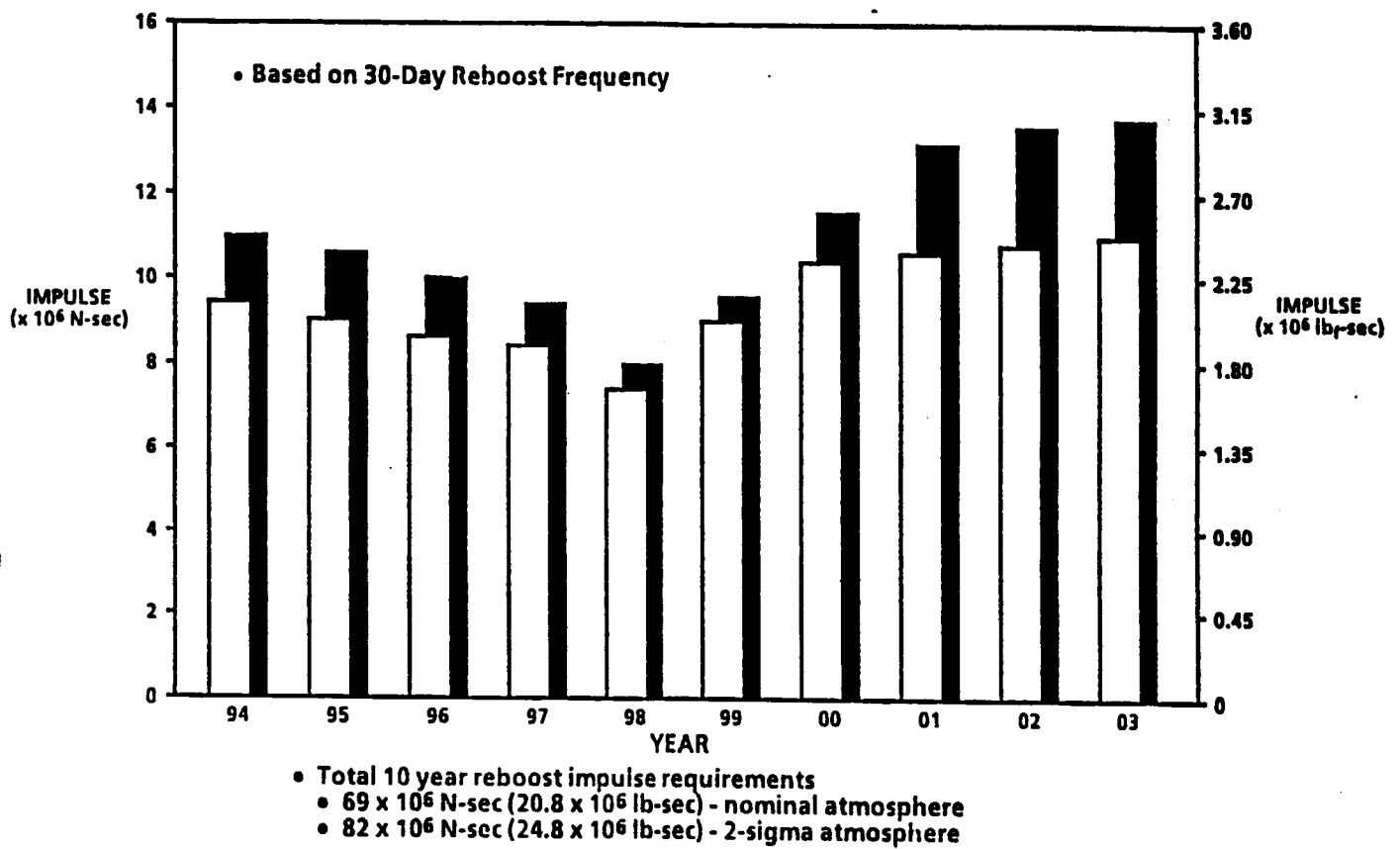


FIGURE 6.7.2-2 2-SIGMA AND NORMINAL ATMOSPHERE ANNUAL IMPULSE REQUIREMENTS

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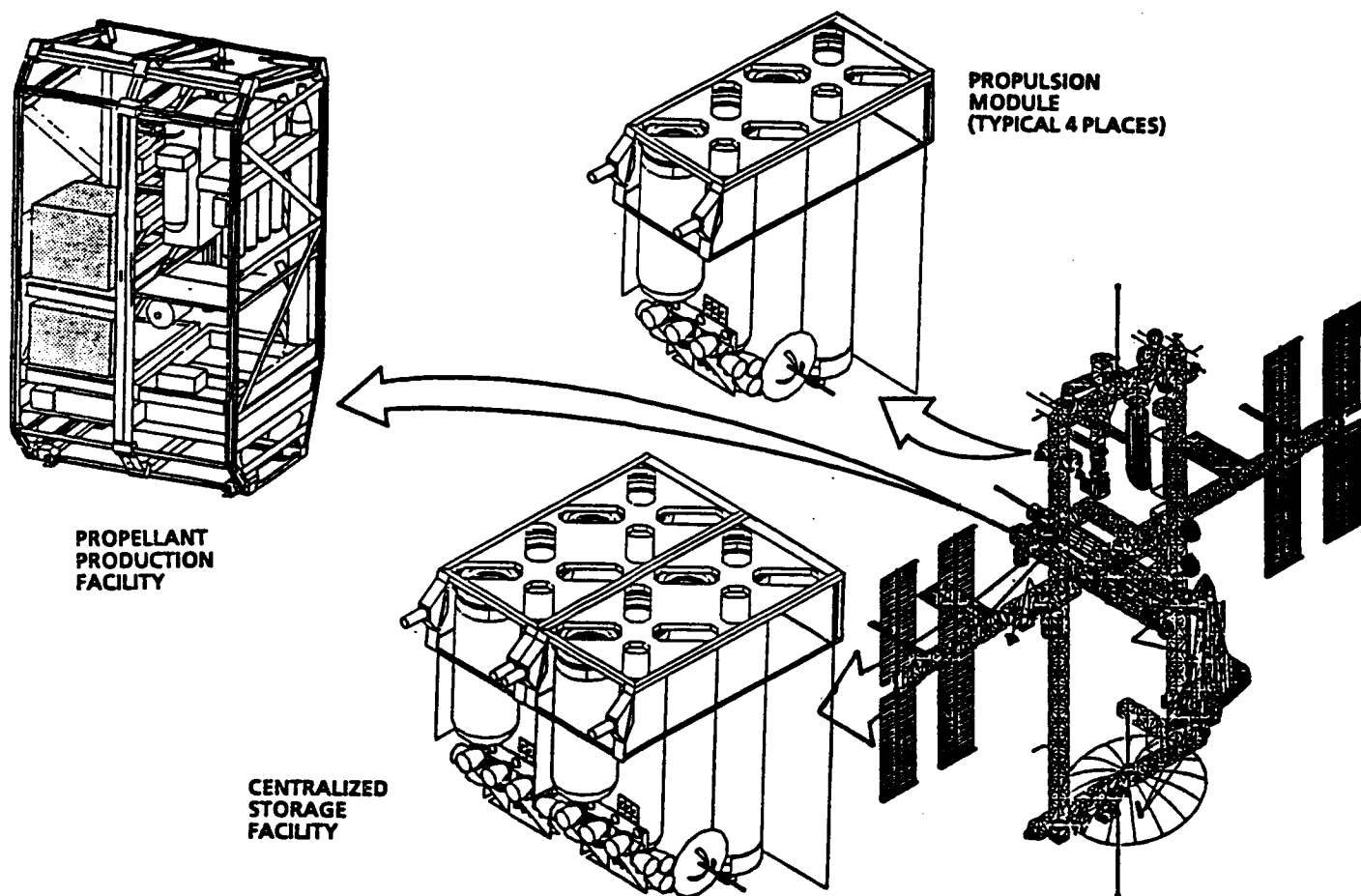


FIGURE 6.7.2-3 SPACE STATION O₂/H₂ WATER ELECTROLYSIS PROPULSION
SUBSYSTEM LOCATIONS

6.7.2.1 Lines and Valves

6.7.2.1.1 The propellant Distribution and Valving

The propellant distribution system of the Space Station O₂/H₂-connected modular propulsion system configuration is designed to provide and control the flow of propellant from the propellant production system to the accumulator tanks in the Central Storage Facility (CSF) and the propulsion modules at the four corners of the Space Station and, finally, to the thrusters. The propellant distribution system will also be able to provide emergency O₂ to the crew and to supply excess H₂, generated by the ECLSS, to the accumulator tanks. Single redundant lines are provided as backup in case of line rupture. Propellant transfer between modules to accommodate shifts in the station center of gravity will also be possible. Approximately 6.35mm (.25 in) lines will be used to distribute the oxygen and hydrogen to the central storage facility and 9.525mm (.375 in) lines from the CSF to the modules. Line heaters and interconnects between lines will not be necessary, due to the extremely low freezing point of oxygen and hydrogen, and to the nature of the capillary lines. Approximately 341.38 mm (1,120 ft) of propellant line is required.

6.7.2.2 Propellant Storage Facilities

Due to the low package efficiency (i.e., low density), both the oxygen and hydrogen require large, high-pressure accumulator tanks to store the required amount of readily available propellant. At a storage pressure of 1,000 psia and a temperature of 200F., the oxygen has a density of 7.051 lbm/ft³ and hydrogen of .391 lbm/ft³. Each propulsion module can store 75,000 lbf/sec impulse or 193 lbm of propellant at a mixture ration of 8:1 under these storage conditions.

The tanks are composite, allowing for lower system weight at high pressure than metallic tanks could offer. The oxygen tanks use an inconel 718 liner with an IM-6 graphite/epoxy overwrap. The inconel liner is used to avoid spontaneous ignition of the oxygen with other metals (i.e., aluminum) when stored at high pressures and struck by high-speed particles

or hydrocarbons. The hydrogen tanks use 6061-T6 aluminum liner with an IM-6 graphite/epoxy overwrap.

Each module has six hydrogen tanks and two oxygen tanks. This allows for better packaging, given the volume constraints during build-up and assembly. It also allows for better fail-safe/fail-operational capability.

6.7.2.3 Avionics/Controller

The propellant utilization and management system is designed to gauge propellant quantities, control intertank propellant usage, control propellant flow rate, control propellant production rates, and to interact with the ECLSS, fluid management system, power, and MTL.

The operational strategy for the O₂/H₂ propulsion system involves feeding off all accumulator tanks simultaneously during thrusting procedures. On a continuous or non-continuous basis, propellant will be generated so that all tanks will have depleted propellant replenished within 30 days of thrusting. Dual isolation valves in both direction on the O₂ lines will allow for emergency O₂ to be sent to the crew modules.

The propellant utilization and management system has temperature sensors and pressure transducers on all tanks, thrusters, and lines, in order to monitor these systems. Components of the Space Station propulsion system will interface directly

with the DMS. The GN&C system will interface with propulsion systems via the DMS.

Additional details can be found in Boeing document D483-50022-5, Vol I (DR-02) dated October 31, 1986.

6.7.3 REBOOST

6.7.3.1 Groundrules and Requirements

The objective of the reboost analysis is to determine the requirements for orbit maintenance and adjustments, and to determine the reboost strategies and procedures. The requirements include the nominal altitude, operating strategy, reboost interval, reboost strategy, thrust location, reboost control strategy, and thrust level. The total mission impulse is made up of impulses for translational and rotational operations. The total impulse is further broken down into contingency and mandatory operations. The IOC station contingency operations include a collision avoidance maneuver, a 20 n.mi. (37 km) altitude transfer, and a 24 day allocation for z-axis attitude control. The IOC station mandatory operations include a reboost maneuver and an allocation for attitude control to accommodate disturbances over and above the momentum management devices (MMD) capabilities.

The IOC reference configuration, as described herein, will be used as the baseline in the trades described in the reboost program plan. The plan is attached for completeness.

6.7.3.1.1 IOC Reboost Requirements

Operating Altitude	250 nm (463 KM)
- Station Elements Flyers /Platforms	Co-Orbiting Free
- Reboost Interval	30-90 Days

- Reboost Strategy	Minimum Altitude
- Thruster Location	Distributed
- Reboost control	Pulse
- Thrust Level	4 (75 to 25 LBf) 4(333.6 to 111.2 N)

Natural Environment - The natural environment is the environment described in the NASA document, NASA TM86498, "Natural Environment Design Criteria for the Space Station Definition and Preliminary Design (2nd Rev)", March 1985. The density model is the MSFC/JTO Orbital Atmosphere Density Model. The document addresses the atmospheric dynamic and thermodynamic environments, meteoroids, radiation, magnetic fields, physical constants, etc.

Nominal Altitude - The baseline nominal altitude for the Space Station is 250 nm (463 Km). This is the planned minimum altitude at the time of shuttle rendezvous. The concept of a variable altitude reboost strategy was approved by the program in order to improve STS payload-to-orbit capability. The variable altitude strategy is described in Section 3.8.

6.7.3.1.2 Propellant

The baseline IOC propulsion system utilizes oxygen and hydrazine propellant.

Thruster Location - The thrusters are located in 4 cluster groups distributed about the center of mass. Each cluster contains 9 thrusters, 3 thrusters directed in the y axis, 3 thrusters directed in the -x axis, and 3 thrusters directed in the x axis. The thrusters are located as shown in the Propulsion DR-02.

Thrust Level - The nominal thrust level for each of the 36 thrusters is 25 lbf

(333.6N). The thrusters are of the regulated type; therefore, the thruster range is 25 lbf yp 21 lbf.

6.7.3.1.3 Operating Strategy

The Space Station will be allowed to decay for 90 days following which the station will be reboosted. The nominal altitude is the altitude at which the station is reboosted to and allowed to decay from. The operating strategy is termed variable as opposed to fixed about a nominal altitude. The Space Shuttle (Orbiter) is docked for 14 out of the 90 day resupply period. The Space Station shall not be reboosted with the Shuttle docked.

Reboost Interval - The time period between the beginning of two succeeding reboost maneuvers is termed the reboost interval. The reboost interval is 30-90 days.

Reboost Strategy - The baseline reboost strategy is termed minimum altitude. The station is reboosted (shortly after the shuttle departs) to an altitude that allows decay back to the minimum altitude in the required reboost interval. Reboost shall not occur with the shuttle docked. A variable altitude reboost strategy is now recommended.

Reboost Control Strategy - The attitude control during a reboost maneuver is performed by the same thruster groups as described in Section 2.1.6. The Space Station's primary attitude control are momentum management devices (MMD) that will be desaturated or locked up during the reboost maneuver, the control strategy is to pulse the active thrusters to attain the desired station attitude control within set limits. The control limits are an attitude of + 5 degrees and an attitude rate of + .02 degrees.

6.7.3.2 Total Impulse Allocation

6.7.3.2.1 Translational Allocations

Collision Avoidance - From the Statement of Work, Requirements C-4.2.2.8(b) and C-3.2.4.3(h) both address collision avoidance. The C-3 requirement gives 24 hours to accomplish a 10 Km maneuver. The C-4 requirement states that the station shall not be reoriented during maneuver and that providing collision avoidance shall not size the propulsion system. The reference configuration provides a 61,500 LBf -s (273,550 N-S) total impulse contingency for collision avoidance, this corresponds to a 396,000 lbm (180,027Kg) station given a 5 ft/s (1.52 m/s) velocity change.

Altitude Transfer 20 nmi (37Km) - The Statement of Work does not have a requirement that addresses this maneuver. This maneuver is in addition to the required 90 days reboost maneuver. The reference configuration provides 831,000 lbf-s (3,696,288 N-s) total impulse contingency for a 20 n.mi. (37 Km) altitude transfer maneuver. The altitude transfer maneuver will be used to transfer the station to a 20 N.Mi. (37 Km) altitude circular orbit (higher or lower). This is to give altitude flexibility. It was not intended to provide reboost backup for a missed (90 day resupply) opportunity.

Reboost Maneuver - From the Statement of Work, Requirements C-3.3.4 (b) and C-4.2.2.8 both address the mandatory reboost maneuver. The major requirement is the 90 day resupply.

The reference configuration reboost interval is 90 days, up to a nominal altitude of 270 nmi (500 Km). The maneuver is a Hohmann transfer from the altitude at the

end of the 90 days to the nominal altitude. The velocity change is 39.3 ft/s (12 m/s) for a 90 day decay of 11.0 N.Mi. (20.4 Km). The total impulse is 483,000 Lbf -s (2,148,384 N-s) for the 396,060 LBm (180,027 Kg) station. This reboost maneuver does not correspond to the worst case solar activity. The reboost maneuver is accomplished by firing one 25 Lbf thruster from each cluster in the direction opposite of flight for approximately 30 minutes (total).

6.7.3.2.2 Rotational Allocations

Attitude Control for 24 Days - Z Axis Only - The above case is a part of the rotational allocation section and is introduced on the basis of a failure of the RCS attitude control subsystem except in the Z-axis (yaw axis) direction. A time factor of 24 days has been selected by NASA with the assumption that this would be the minimum turn around time for a shuttle to be launched.

The Z-axis only direction was selected for the reason that if no attitude control system were active the space Station would be oriented to a position where the solar array boom would be aligned in the orbit plane thereby causing difficulty for the solar arrays to track the sun resulting in a reduction of power output and a possible malfunction of Space Station activities. The given value, in Table 6.7.3.2.2-I, of angular momentum for this case at a moment arm equal to 68 ft. is 10,000,000 ft-lb-sec. This number is presented as the approximate amount of angular momentum necessary to keep the proper attitude of the station in the Z only axis direction. The proper attitude of the station is defined as having the solar array boom perpendicular to the orbit plane when in steady state flight.

Orbiter Capture and Orbiter Berthing - In Table 6.7.3.2.2-I in the rotational allocation section values of moment arm length

and angular momentum are given for orbiter capture and orbiter berthing. Both have identical values for the moment arm which is 88 ft. and is measured from the centerline of the orbiter docking port to the center of mass of the Space Station. The berthing angular momentum value, of 1,500,000 ft-lb-sec, includes the Space Station mass plus the orbiter mass. Thus, with the additional mass of the orbiter anchored at the Space Station, the required impulse needs to be increased if proper attitude is to be maintained for the duration of the orbiter stay. Therefore, the capture angular momentum, 150,000 ft-lb-sec, does not include orbiter mass but probably takes into account the disturbance torque generated by the orbiter when trying to dock. Module Berthing - Table 6.7.3.2.2-I also shows that for module berthing the same moment arm of 88 ft is used. This procedure of module berthing assumes that the value of the angular momentum, 500,000 ft-lb-sec, is the sum of each module being unloaded and berthed by the orbiter RMS from the shuttle cargo bay.

6.7.3.3 Resupply Scenario's

Resupply Scenarios are dependant upon the selection of propellant, (N_2H_4 or O_2/H_2). The baseline propellant was changed 7-86 to be O_2/H_2 , allowing integration of the propellant fluid system with all other SS systems utilizing water and O_2/H_2 gases. Strategy calls for utilizing excess water obtained from the STS orbiter while the orbiter is docked to S.S. Therefore the amount of available propel

TABLE 6.7.3.2.2-I REFERENCE CONFIGURATION IMPULSE ALLOCATIONS

TRANSLATIONAL ALLOCATION	MOMENT ARM (FEET)	ANGULAR MOMENTUM (FT-LB-SEC)	90-DAY RE-SUPPLY IMPULSE (L3-SEC)	90-DAY RE-SUPPLY N ₂ H ₄ 9LBS	CONTINGENCY IMPULSE (L3-SEC)	CONTINGENCY N ₂ H ₄ (LBS)
• COLLISION AVOIDANCE AV - 5FT/SEC	--	--	--	--	61,500	--280
• ALTITUDE TRANSFER 20 N. MILES	--	--	--	--	831,000	3,780
• REBOOST 90 DAYS AT 270 NM (MIN)	--	--	483,000	2,300	--	--
ROTATIONAL ALLOCATION						
• ATTITUDE CONTROL 24 DAYS - 2 AXIS ONLY	63	10,000,000	--	--	147,500	670
• ORBITER CAPTURE	88	150,000			--	--
• ORBITER BERTHING	83	1,500,000	26,000	120	--	--
• MODULE BERTHING	83	600,000			--	--
N ₂ H ₄ RESUPPLIED EACH 90 DAYS (LOCATED IN LOGISTICS MODULE)	--	--	509,000	2,320	--	--
N ₂ H ₄ CONTINGENCY (LOCATED ON STATION)	--	--	--	--	1,339,500	4,730

TOTAL AVAILABLE 1,548,500 LB-SEC - 7,050 LBS- N₂H₄

lant is dependant upon the frequency of shuttle rendezvous with S.S. The propellant quantities are resupplied during the shuttle stay period.

6.7.3.4 ECLSS Augmentation

The Environmental Control and Life Support System is a major user of water, oxygen, and hydrogen. The ECLS System utilizes electrolysis to convert liquid H₂O into Hydrogen and Oxygen gases, just as the propulsion system. The ECLS System can therefore be highly integrated with and supplemented by the O₂/H₂ propulsion system. For a more detailed description, See Volume I of this document.

6.7.3.5 OMV Options

Utilization of OMV during the S.S. life cycle is not recommended because of the inherently lower performance of the OMV propellants with respect to the S.S. O₂/H₂ propulsion system.

Utilization of OMV for reboost is considered primarily for the initial phase of S.S. assembly. Flight altitude may have to be low in order to increase STS payload to orbit so that the propulsion system reliability is most critical. Because OMV is scheduled to be flying in 1991, the system will be proven for use during this time.

6.7.3.6 Subsystem Commonality

Propulsion subsystem equipment commonality is found with ECLSS subsystems, especially in that equipment required for high pressure water electrolysis.

6.7.3.7 FOC

The reboost requirements for the FOC Space Station are entirely dependent on the actual growth of hardware attached to the SS. The characteristics most pertinent to the reboost requirements are:

- 1) total S.S. mass and
- 2) drag area

The Space Station mass directly effects the required impulse to achieve a given change in orbit velocity. As S.S. total mass increases, so does the total reboost impulse requirement. The S.S. drag area effects the rate at which the S.S. orbiter decays due to drag, with greater drag area leading to increased rates of decay, and consequent increased magnitude of S.S. reboost. Mass and drag area are related in the expression for ballistic coefficient, which indicates the relative magnitudes of orbit inertia and the drag forces experienced by an orbiting body. The actual growth of S.S. is undefined at this time. For the purpose of trade studies and lifetime altitude projections various assumptions have been made. Including that of linear growth in Mass and proportionate growth in drag area. Specific assumptions are indicated where appropriate in the trade study section of this document.

Additional detail can be found in Boeing document D483-50022-5 Vol II (DR-02) dated October 31, 1986.

6.8 Airlocks

6.8.1 EVA Airlock

The Airlock is a Space Station element which provides a means of exiting the Space Station Habitable Modules whenever the astronaut wishes to engage in Extra Vehicular Activity (EVA). The Airlock is comprised of a Structural Subsystems; a Meteoroid/Debris Protection System; an Environmental Control Life Support System (ECLSS) TCS, Internal Comm and EPS distribution, an internal Structural Support System; and there is a Docking/Berthing System at the Hatchway that will be connected to a Space Station Element.

The Structural Subsystem consists of a 3657.6mm (144 in) diameter which includes a standard docking port. The Hatch/Latch Assembly at each of the access ports are identical and are interchangeable one with another and are also identical to that pair used on the Common Module.

6.8.2 Hyperbaric Airlock

The Hyperbaric Airlock is a Space Station element that provides a pressure environment in excess of the 14.7 psia atmosphere of the Space Station (up to 5 ATM). Its presence will allow an astronaut who is suffering from an air embolism or the bends to be placed in a pressure several times greater than that of the modules. The Hyperbaric Airlock is comprised of a Structural Subsystem; a Meteoroid/Debris Protection System; TCS, ECLSS, IC & EPS distribution, an internal Structural Support System; and there is a Docking/Berthing System at the Hatchway that will be connected to a Space Station Element.

The Hatch/Latch Assembly at each of the access ports are identical and are interchangeable one with another and are also identical to that pair used on the Common Module.

6.9 Resource Nodes

The Resource Nodes (4) are Space Station Elements which provide connection between the various modules, airlocks, STS berthing adapters and attached payloads. Each node is comprised of a Structural Subsystem; a Meteoroid/Debris Protection System; a Thermal Control System; an ECLSS, Internal Communications, IC & EPS an internal Payload Support System; and there is a Docking/Berthing System at each of ten Docking Ports.

The Structural Subsystem consists of two conical end bulkheads, each of which in-

cludes a standard docking port, and a cylindrical section that is formed from three barrel sections. The two end barrels each contains four radial access ports. The barrel sections are welded to the end bulkheads at a large 2219 aluminum forged ring on which a pair of support trunnion fittings and a keel pin fitting have been welded. The two docking port barrel sections are welded at their inner edge to a cylindrical section made up of a pair of forged 2219 rings welded to a waffle stiffened cylinder. In the interest of reducing program costs, the structural subassemblies that comprise the Structural System are identical to those forming the structural subsystem of the Common Module and are assembled on the same tooling. The Hatch/Latch Assembly at each of the access ports are identical and are interchangeable one with another and are also identical to that pair used on the Common Module.

The internal Payload Support Structures of the Interconnect is formed of the same structural components as the Common Module payload support structure, but because the Internal Subsystems of the Interconnect, the Thermal Control System, is a modification of the Common Module Thermal Control System, it is supported on a customized support. The ECLSS, IC, TCS and EPS are common subsystem derived from the HAB USL.

6.10 Habitation Module

The Habitation Module (HAB Module) is the Space Station Program Element which provides for station operations and off-duty crew accommodations.

The HAB Module is comprised of a structural shell, mechanisms, utility distribution, subsystems, and outfitting. HAB Module to Station interfaces occur at the pressure shell for utilities and the external

mounting points for structures. HAB Module to other module interfaces occur at the hatches and hatch utility penetrations.

Four equally spaced utility distribution chases and rack support structure, stand-offs, carry utilities, rack structural loads and distribute cabin air and lighting. Standardized interface plates and quick disconnects transfer utilities from the standoffs to the racks.

Subsystem and utility distribution schemes and structural shell and mechanism commonality exists between the HAB Module and other modules. The HAB Module has modified ECLSS plumbing to support crew functions.

HAB Module rack layout configuration is shown in Figure 6.10-1.

6.10.1 Crew Quarters

Eight crew quarters are provided, one for each IOC crewmember. Each crew quarter occupies the volume of 2.5 single racks. The major internal volume in each crew quarter is the two single rack area with the remaining half rack being a shared utility core with the adjacent crew quarter. This provides acoustic insulation between crew quarters for privacy.

Entry into the crew quarter is through a specially designed door. This provides area for storage in the crew quarter and does not impact egress requirements. Sleep restraints can be detached and placed in various positions to suit an individual's orientation preference for sleep, reading, etc. The aisle facing wall is thick, providing stowage and acoustic isolation. Provisions for adding radiation shielding to crew quarters walls and ends are in-

cluded at part of the basic compartment design.

6.10.2 HMF Exercise Area

Three single racks are provided for the exercise area and equipment stowage. Provisions are included for mounting a multitude of exercise devices (e.g. a rowing machine, bicycle ergometer or treadmill) in the compartment. A window is provided for recreational viewing during the exercise period. Audio and video are also provided for entertainment.

Controlled airflow is directed over the exerciser, from head to foot direction. Force reaction for exercising is provided by adjustable padded restraints. The exercise devices are designed to be mounted also on any rack front to allow them to be moved the the crew to optimal locations to minimize noise, odor or congestion.

6.10.3 HMF Medical Facility

Three single racks are provided for containment of GPE medical diagnostic and treatment equipment.

6.10.4 Wardroom

The wardroom uses three double racks to provide seating for eight crewmembers. Two tables can extend to accommodate all crewmembers at one time. Two windows are provided, one at each end of the table. Display monitors can be positioned over the windows for communication or entertainment viewing. This allows the primary viewing at either window or monitor. Stowage is provided under the tables. The wardroom occupies space equipment to three double racks.

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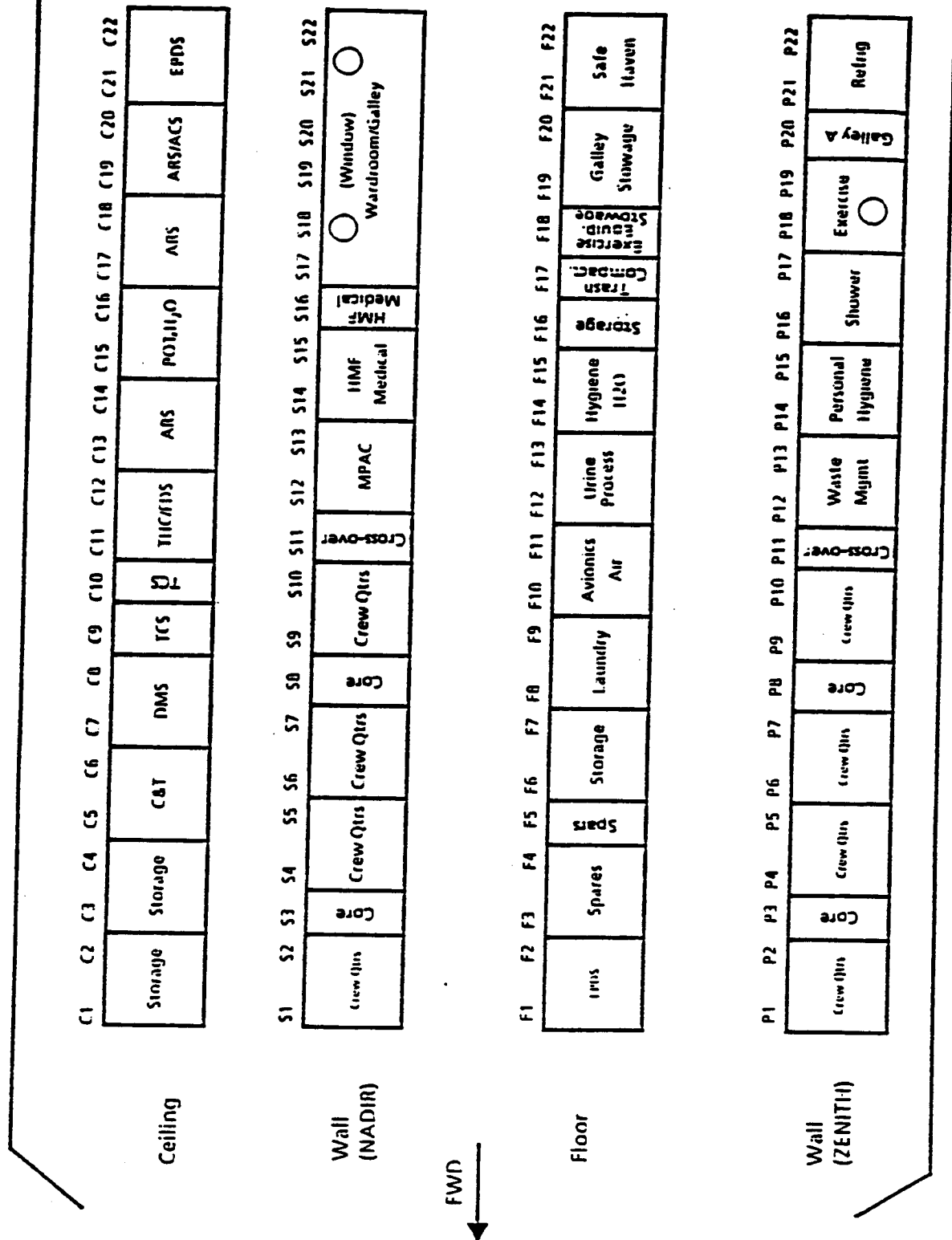


FIGURE 6.10-1 HAB MODULE RACK LAYOUT

FIGURE 6.10-1 HAB MODULE RACK LAYOUT

6.10.5 Waste Management

A commode, urinal, handwash and vacuum are provided to accommodate body waste and subsequent cleanup. A double rack is allocated for this function.

Adjustable foot restraints are provided to allow for correct foot positioning while using the commode. Storage is provided for ancillary equipment and consumables such as disposable wipes.

6.10.6 Galley

Three double racks contain the equipment and storage necessary to provide meals for eight crewmembers for fourteen days. A handwasher and dishwasher are included within the galley for both water dispensing and post-meal cleanup.

Two ovens are provided for simultaneous heating of food for all eight crewmembers.

6.10.7 Shower

A double rack contains the shower/dressing room. A movable partition separates the two areas. When the crewmember is dressing or undressing, the partition is moved to increase the size of the dressing area. As the crewmember steps through the dressing area to shower door (in the movable partition), the partition is moved to increase the size of the shower.

A liner protects the shower from contamination. After a given interval, the liner is removed and cleaned or disposed. This prevents long term accumulation of bacteria or fungus in the shower. It also makes cleanup after each shower less demanding.

A Skylab type shower restraint is used for stability. A shower head/vacuum pickup is located on a flexible stalk. Airflow is directed from head to toe direction. Tempo-

rary storage for clothing is provided in the dressing area.

6.10.8 Laundry

A double rack contains a combined washer/dryer. When clothes are placed in the device, it first washes them using a nested perforated drum, rotating inside a larger sealed drum. When the clothes are clean, the water is removed using centrifugal force and a fan separator. Warm air is then passed through the clothes while they are spun, until they are dried.

6.10.9 Multi-Purpose Applications Console (MPAC)

The MPAC fits within a double rack. It provides both Station control and proximity operations control. Internal and external control functions are provided as well as OMV and NSTS proximity operations. The MPAC has a multifunction keypad, a alphanumeric keypad and redundant six degree of freedom controllers as well as two visual display monitors.

The MPAC also functions as the DMS crew interface. A portable MPAC is provided for command and control functions which are not performed at the MPAC station.

6.10.10 Reserved

6.10.11 Storage

Storage racks are provided for several categories of storage. Included are crew consumables, on-board spares and equipment.

6.10.12 Safe Haven

One single rack stores equipment, food and supplies for a crew of eight for 28 days.

6.10.13 Electrical Power Distribution System

The HAB Module Electrical Power Distribution System (EPDS) receives power from the Space Station electrical power generation system through penetrators (connectors which penetrate the pressure shell). Power is distributed internally and to ports for distribution to attached elements. Figure 6.10.13-1 shows the Electrical Power System Distribution Architecture.

The HAB Module has two penetrators, two 25 kW Primary Power Distribution Assemblies (PPDA).

The PPDA receives power from the penetrator and distributes power to the SDAs and ports. It contains RCCBs which protect output cabling and provides a means for bus reconfiguration.

The SDAs distribute power to the standoff interface plate. It contains RCCBs which protect the cabling to the interface plates and provides a means for load management. There are no components of the EPDS in the user racks. Figure 6.10.13-2 depicts the EPS Module layout.

6.10.14 HAB Module Thermal Control Subsystem

The HAB Module TCS consists of a single-phase, pumped-water loop that absorbs waste heat from the module interior and transfers it to the station central heat rejection system through external interface heat exchangers. A portion of the heat is rejected to both the 35 and 70 degree F central thermal utility buses. The HAB Module subsystem loop provides coolant to life-critical module loads such as ECLSS, DMS, EPDS and COMM. The thermal transport capacity of the HAB

Module internal loop is 22 kW. A functional schematic is shown in Figure 6.10.14-1 to illustrate the flow connectivity of this loop. The TCS includes a subsystem controller with manual override that automatically maintains coolant flow and interfaces with the DMS. A single-phase water loop satisfies cabin safety and minimum development cost considerations. Two-fault tolerant (fail-operational/fail-safe) requirements are satisfied by redundant plumbing/pumping systems. TCS components are designed for on orbit service, replacement, repair and minimum noise generation. Fluid disconnects are provided at component interfaces to facilitate maintenance. The subsystem TCS is a closed coolant loop and, during operations, does not require expendable resupply.

The HAB Module external structure is wrapped with MLI blankets to thermally decouple the module from external environment changes.

6.10.15 Data Management System (DMS)

The Habitability/Station Operations Module (HAB Module) Data Management System (DMS) provides for data acquisition and control, data processing, data routing, data storage, and retrieval, and subsystem monitoring and control. These functions will be provided to the user via a fault tolerant computer system implementation utilizing a hierarchy of networks and computer products. The following sections detail the DMS.

6.10.15.1 Computer Components

The HAB Module DMS consist of the following components to provide the data acquisition, control, and processing functions.

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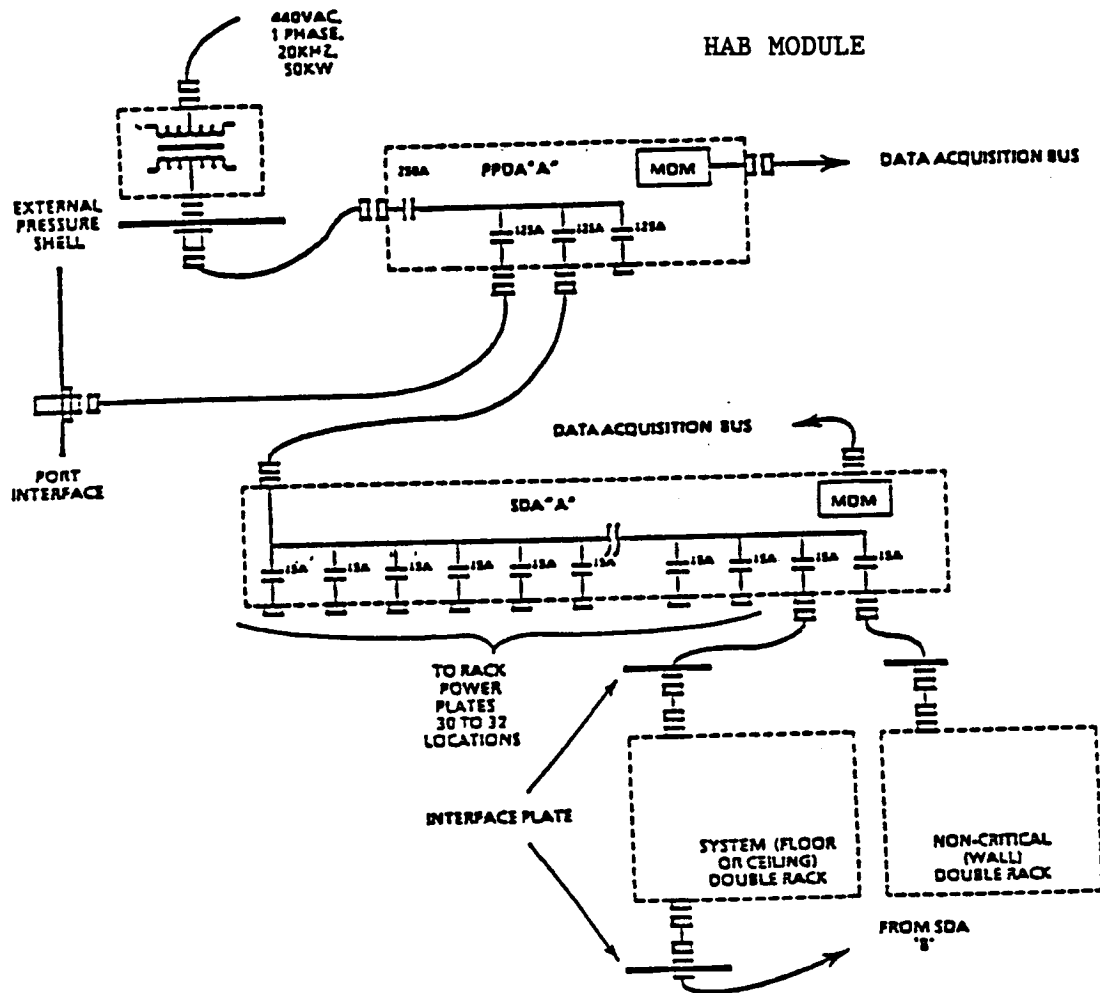


FIGURE 6.10.13-1 EPS FUNCTIONAL DIAGRAM

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FIGURE 6.10.14-1 HAB MODULE TCS FUNCTIONAL FLOW SCHEMATIC

6.10.15.1.1 Standard Data Processor

The Standard Data Processor, (SDP) will be a 32 bit, virtual addressing, space qualified, low power computer that will provide the resources necessary to manage the subsystems in the HAB Module. The SDP will service the following subsystems:

- OMA (Operations Management Applications)
- DMS (Data Management System)
- EPDS (Electrical Power Distribution System)
- TCS (Thermal Control System)
- ECLSS (Environmental Control and Life Support System)
- C&T (Communications and Tracking)

Multiplexer/Demultiplexer

The Multiplexer/Demultiplexer (MDM) shall be a shared resource allocated in a per rack basis that will provide data acquisition and control functions. The MDM will be able to acquire signals from the various subsystems attached to it using the following signal formats:

- +5 VDC discrete inputs
- +28 VDC discrete inputs
- +/-5 VDC analog inputs

The MSM will also be able to generate the following signals for control of attached subsystems:

- +5 VDC discrete outputs
- +28 VDC discrete outputs - +/-5 VDC analog outputs
- +28 VDC relay driver (100 mA)

In addition to the above signals, the following busses will be provided:

- RS-232
- RS-422
- IEEE-488

6.10.15.1.2 Mass Storage Unit

The Mass Storage Unit (MSU) will provide 300 Mbytes of volume shadowed storage on hard disk. This Media shall be used for program load, data base storage, subsystem resource schedules and logs, resource accounting data bases, and temporary data storage for local processing, training, and entertainment.

6.10.15.1.3 Embedded Data Processor

The Embedded Data Processor (EDP) is a single board computer consisting of a 16 bit microprocessor, 1 Mbyte of RAM, 128 Kbytes of EEPROM, and an interface to a standard computer backplane. The EDP is used for management of various computing and networking components, such as the MDM or the BR (see next section).
Networking Components

Network Interface Unit

The Network Interface Unit (NIU) is a single board implementation of the interface required to communicate between the computer backplane and the Data Acquisition, Module Data, or Station Data Bus. There are four varieties of the NIU:

- 1- 10 Mbps on EDP style backplane
- 2- 10 Mbps on SDP style backplane
- 3- 100 Mbps on SDP style backplane
- 4- 100 Mbps on EDP style backplane

Item 1 is used in the MDM to communicate to the Data Acquisition Bus; item 2 is used in the SDP to communicate with the Data Module Data Bus; item 3 is used in the SDP to communicate with the Module

Data Bus; item 4 is used in the Bridge (see next section) to communicate between the Module and Station Data Busses.

6.10.15.1.4 Bridge

The Bridge (BR) is a combination of two type 4 NIU's and one EDP that performs the data buffering and routing necessary between the Station Data Bus and the Module Data Bus.

6.10.15.1.5 Data Acquisition Bus

The Data Acquisition Bus (DAB) is a coaxial cable used to route data from MDM's to SDP's and vice versa. The data rate on the DAB is 10 Mbps and access protocol is via a virtual token ring implemented on a bus.

6.10.15.1.6 Module Data Bus

The Module Data Bus (MDB) is a fiber optic cable used to route data and programs between SDP's MSU's and MPAC's. The data rate on the MDB is 100 Mbps and access protocol is via a virtual token ring implemented on a bus using a star coupler.

6.10.15.1.7 Station Data Bus

The Station Data Bus (SDB) is identical to the MDB, allowing communications between modules, interconnects, airlocks, and external payloads.

6.10.15.1.8 Workstations

The workstations (or Multi-Purpose Applications Console - MPAC) provided by WP-01 are a common interface to the DMS, the subsystems, and all Space Station elements and payloads. There will be two types of workstations available for use on the Space Station: Fixed and Portable.

6.10.15.1.9 Fixed MPAC

The Fixed MPAC (FMPAC) is a double rack unit with the following hardware elements in it:

- Dual display CRT's
- Keyboard
- Caution and Warning displays -Speaker/Microphone unit (Audio subsystem)
- Audio recorder (Audio subsystem)
- Dual video recorders (Video subsystem)
- SDP
 - Graphics processor
 - Video frame grabber/processor
- MDM
- Hardcopy unit

6.10.15.1.10 Portable MPAC

The Portable MPAC (PMPAC) is a laptop sized unit with the following hardware elements in it:

- Flat panel display
- Keyboard
- Joystick
- Partial MDM
 - EDP
 - RS-232 interface card
 - Analog/Digital interface card
 - NIU, type 1
- Power conditioner

With these components, the PMPAC can be connected at any location where a DAB tap is located. Power levels in the packaging of the PMPAC will be such as to allow for radiational cooling.

6.10.16 Structural and Mechanical Components

6.10.16.1 Pressure Shell

The HAB Module pressure shell is an all welded 2219 aluminum shell with 300 conical end bulkhead. The Shell has a 450 waffle grid with ribs on the outside and a smooth surface on the inside. As shown in Figure 6.10.16.1-1 the module is 4616.4mm (166 in) inside diameter, 4445mm (175 in) outside and 11784.2mm (464.14 in) cylinder length.

The shell has a pressure carrying skin which is 3.175mm (.125 in) thick. The ribs are 2.286mm (.09 in) thick and 22.225mm (.875 in) high and are optimally spaced to carry the appropriate loading and torsions. The shell panels are rolled before welding into a 90 degree segment of the skin. Four of the 90 degree segments are welded longitudinally to form a cylindrical section.

The basic shell has a fairly large ring forging that is welded to the end bulkheads and the cylinder section adjacent to it. There is, in addition, a pair of intermediate rings of a somewhat reduced cross section that also act to stabilize the pressure shell during lift off or landing load events. These rings are carefully sized to insure that the cylindrical section buckling loads are consistent with the shell panels between stiffeners (ribs).

The rings also provide for the mounting of the trunnions and the keel pin. The shuttle load doctrine requires the longitudinal thrust load to be carried by the aft pair of trunnions. Two longitudinal shear beams are provided to shear the thrust loads into

the shell and to-beam the kick loads resulting from the local eccentricity into areaction at the keel pin ring and the aft trunnion ring.

6.10.16.2 Hatches

There is a pressure hatch built into the docking port in the center of each of the end bulkheads. The hatch has a square opening 1270mm (50 in) on each side with the corners rounded off at a twelve inch radius. There are 16 latches equally spaced around the opening which will act to carry the hatch load if the hatch is called on to support a reversed pressure situation that occurs, if the interconnect is pressurized but the module is not. Each hatch has a 6 inch diameter window. The hatches slide on tracks during opening and closing and are adapted from a 767 door. This arrangement allows good storage and takes up less space.

6.10.16.3 Windows

There are provisions for 3 windows 20 inches in diameter in the basic design. Two basic concepts were investigated. Because of the load paths and stress pattern while on-orbit and under pressure, a configuration of a window that would conform to the cylindrical curvature of the shell was investigated as was a conventional circular (flat) porthole type window. The conventional porthole appears to be a lower weight system and was therefore selected.

6.10.16.4 Secondary Structure

The subsystems and payloads inside the shell are supported by four equally spaced standoffs. These standoffs are candidates for fabrication out of composite materials as an alternate to conventional aluminum shapes. In either event, the stiffness of structural members that comprise the se-

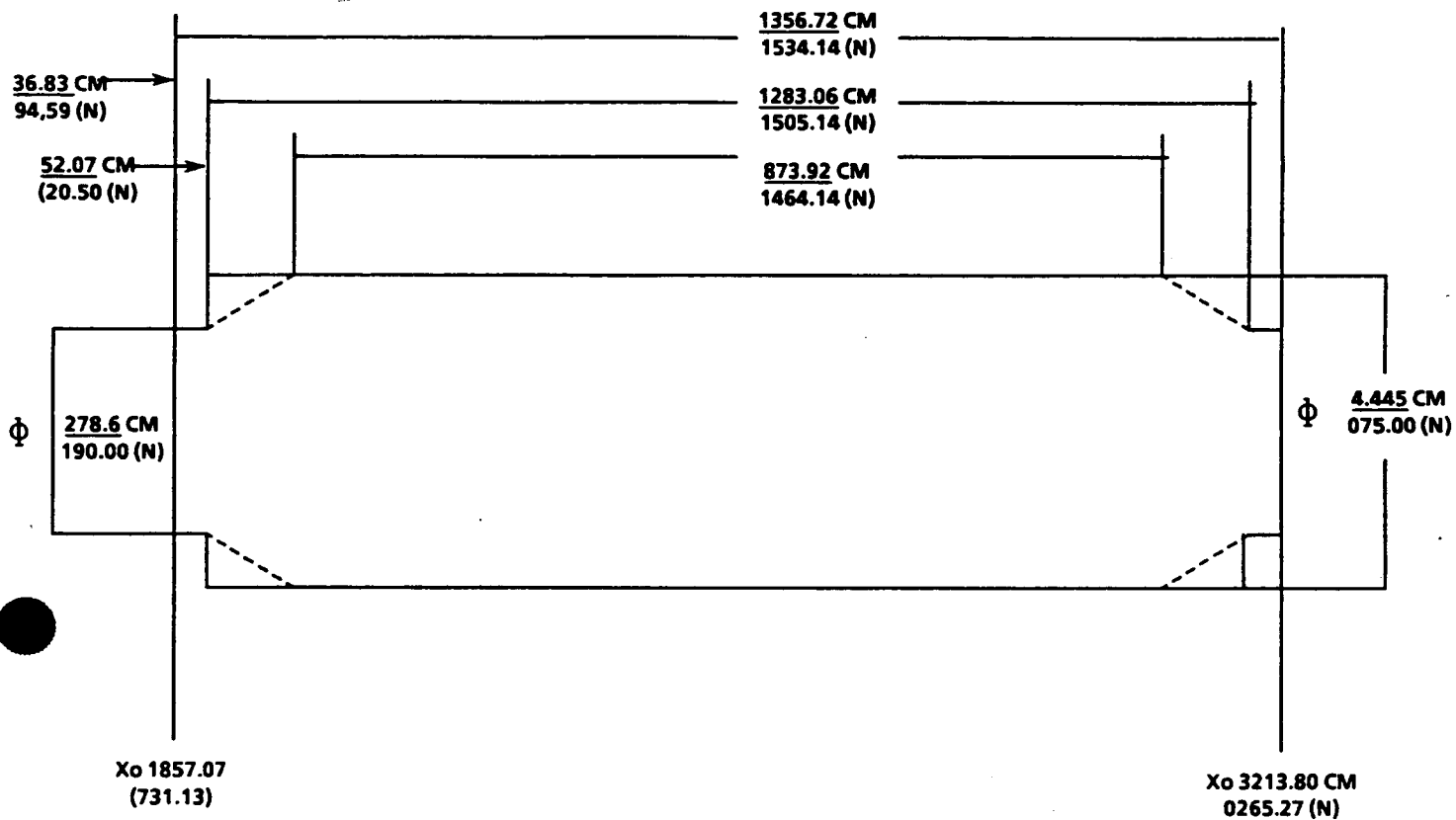


FIGURE 6.10.16.1-1 HAB MODULE/ORBITER CARGO BAY ENVELOPE

condary structure will be tuned to be consistent with the shell stiffness to keep the interface loads to a minimum during shuttle flight events. A meteoroid-debris shield which is 1.016mm (0.040 in) thick 6061 aluminum is installed with a 4.5 inch standoff to protect the pressure shell.

6.10.16.5 Structural/Mechanical Subsystem

The HAB Module Structural/Mechanical Subsystem consist of the following major components:

- Standard single racks
 - Standard double racks
 - Rack restraint system
 - Utility routing support structures
 - External end cone-mounted truss for consumable tank storage
 - End-cone utility feed
 - through bulkheads
 - Vibration isolation system assemblies
- #### Standard Racks

The standard single rack is 1892.3mm (74.5 in) high by 546.1mm (21.5 in) wide by 914.4mm (36 in) maximum depth and has a standard hole pattern to accept panel-mounted equipment per MIL-STD-189, i.e. the standard front panel width is 482.6mm (19 in) and the center distance of the mounting holes is 464.82mm (18.3 in). The maximum opening between the front panel mounting flanges is 451.1mm (17.76 in) and the maximum corresponding width for equipment housed within the single rack is 442.5mm (17.42 in).

Each single rack houses Avionics supply and return air ducts and a fire suppression bottle assembly in the rear portion of the rack, as well as standard subsystems interface panel occupies approximately 6 in. of rack height, and the Avionics ducting occupies approximately 6. in of rack depth the rack design allows for the attachment of equipment to the inside surfaces of the four corner posts via standard hole patterns and light-weight attach rails.

The standard double rack is effectively two single racks sharing common center posts at the front of and rear, and a central segmented bulkhead which is removable. The overall width of the standard double rack is 42 in.

6.10.16.6 Rack Restraint System

Rack restraint systems which have been considered include the following:

- a. a sliding rail/guide system employing double rails at the top and bottom of each rack
- b. a statically determinant mounting system similar to the Spacelab rack attachment system. This arrangement consists of a fastener at each lower front corner (each reacting X, Y, and Z loads), and two adjustable struts between the top of each rack and the USA Laboratory shell structure (reacting X and Y loads while allowing the USA Laboratory shell to "breathe" relative to the rack structure).

6.10.16.7 Communications Systems

The communications systems in the HAB Module consist of an internal audio and video system. These systems are described in the following sections.

6.10.16.8 Audio System

The audio system in the module (See Figure 6.10.16.8-1) consists of several C&T rack mounted components which control the audio system, and distributed elements in the working areas of the module.

The C&T rack mounted components are the audio controller, audio terminal unit, and audio interface unit. The audio controller is the interface to the audio system, for such things as caution and warning messages, and receives status information about the audio portion interface to the end to end audio system. It allows crew members to communicate via the wireless system to any part of the station or to the ground. The audio interface unit is the interface to the external C&T equipment which allows crew members in the USL Module to communicate to the ground or to other SS elements.

This distributed elements of the audio system in the HAB Module are the speaker microphone, audio recorder, and the crew wireless units. The speaker microphone located in the bulkheads, crew quarters, health maintenance facility, wardroom, galley, and MPAC, is the element by which crew members access the audio system. It consists of a speaker, microphone, keypad (to select the various operational modes) and an optional jack for using a headset. From the speaker microphone a crewmember can access any internal station location or the ground. The audio recorder is located in the MPAC and is available via MPAC control to record two channels of audio communications upon demand. The crew wireless units are used

to access the wireless communications system. From the wireless units a crew member can access any internal station location and the ground.

The elements of the audio system are interconnected by a station audio bus. These buses run through out the station allowing intermodule audio communications. The bus switching unit, located at either end of the USL module allows the module to be isolated from the rest of the station in case of a failure.

6.10.16.9 HSO Video System

Operation of the video system in the HSO Module (See Figure 6.10.16.9-1) is similar to operation of a broadcast studio. The system uses a 32 x 16 baseband video switch. This switch, operating under control of the Control and Monitor subsystem, establishes proper interconnection of sources and sinks. Possible sources in the HSO include a video camera located at each end of the module on the endcone, two video recorders located in the MPAC, TBD sources from structure mounted cameras, TBD inputs from WP-02 RF links, and 8 sources from the interconnects (this includes intermodule baseband sources).

Possible sinks include 2 video monitors and two video recorders in the MPAC, TBD outputs to the WP-02 RF links, one monitor in the galley, and 8 links to the interconnects (this includes intermodule baseband links).

There will also be ten reconfigurable I/O ports evenly spaced throughout the module. These will be used for portable cameras or monitors at various places throughout the module.

Cameras will have the capability of generating a test signal to test the signal characteristics of the path between the camera and any link location. There will also be a

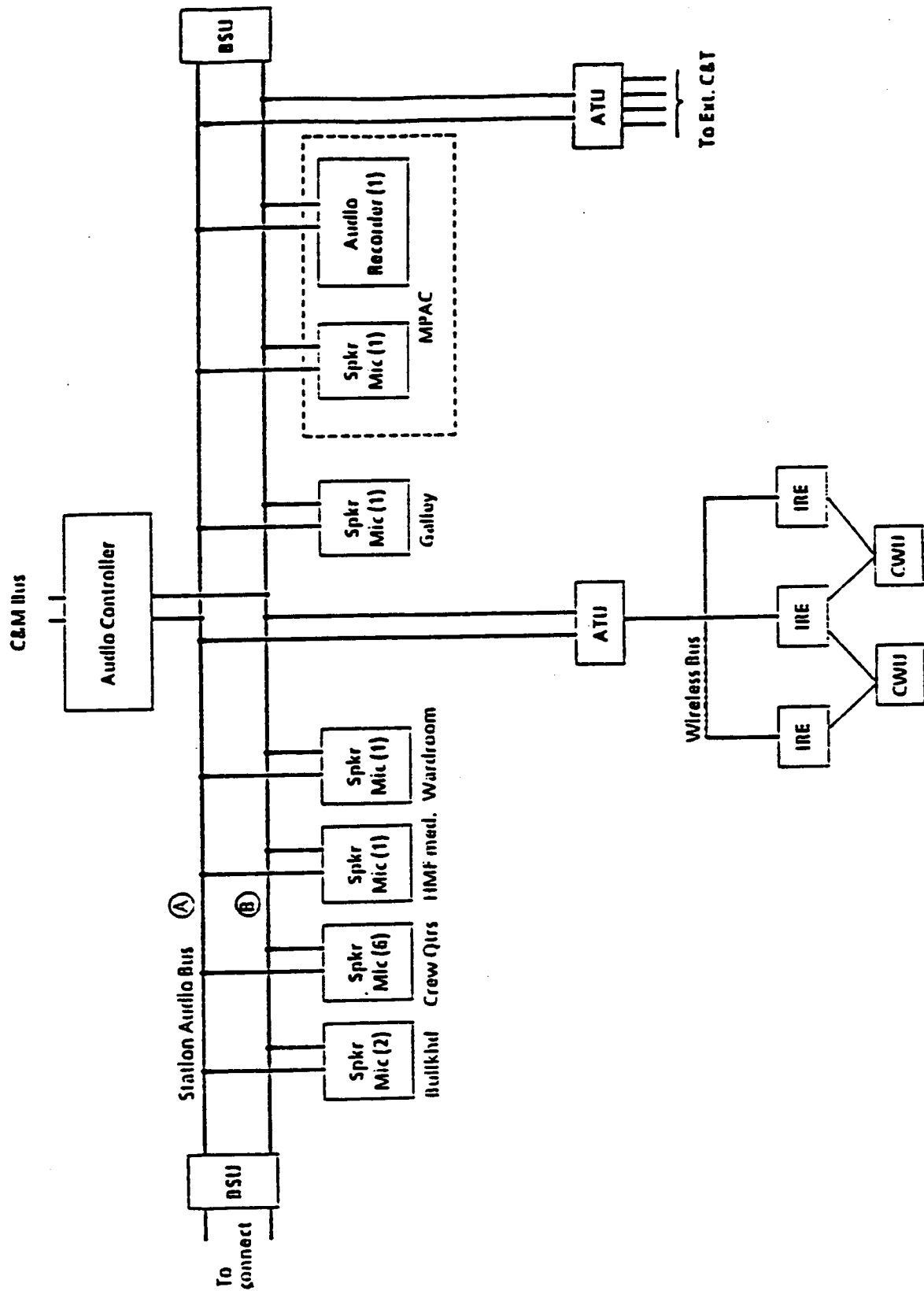


FIGURE 6.10.16.8-1 HAB MODULE AUDIO SUBSYSTEM

FIGURE 6.10.16.8-1 HAB MODULE AUDIO SUBSYSTEM

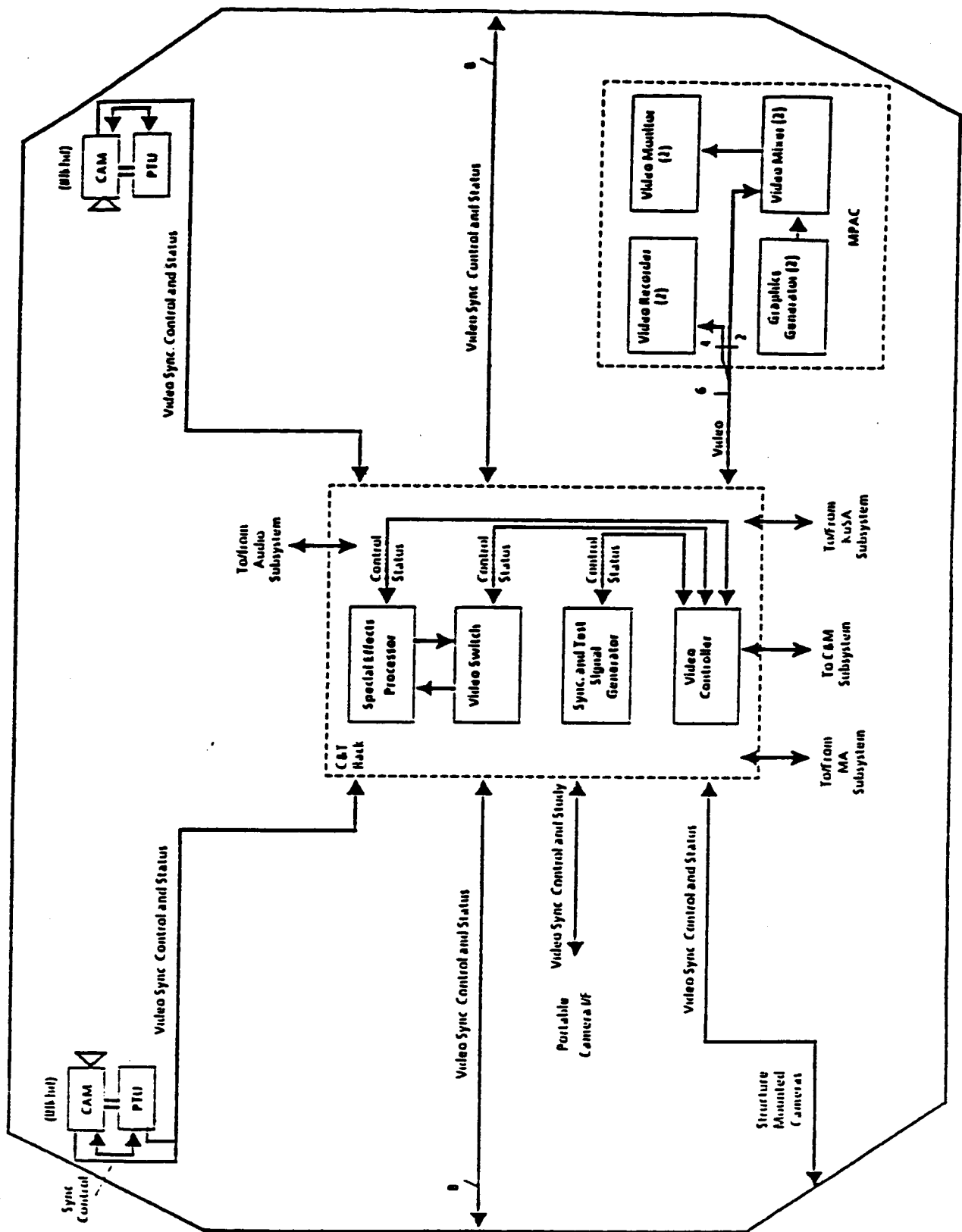


FIGURE 6.10.16.9-1 VIDEO ARCHITECTURE

FIGURE 6.10.16.9-1 VIDEO ARCHITECTURE

test signal generator in the C&T rack used to test the signal path from the switch outputs to the link devices and to the ground.

A sync. signal will be generated and sent to each camera to allow multiscreen displays as well as limit crosstalk. Special effects for multiscreen display will be generated in the C&T rack and looped back to the video switch for distribution to the selected sink device. Graphics overlay of the video will occur in the MPAC.

6.10.17 ECLSS

The Environmental Control and Life Support Subsystem (ECLSS) provides and maintains a healthful, comfortable shirtsleeves atmosphere in the pressurized volumes of the space station; provides clean water for the crew consumption and sanitation; and collects, processes and stores waste materials for return to the Earth. Related services are provided to equipment/experiment racks. Figure 6.10.17-1 is a total ECLSS schematic diagram. The HAB Module ECLSS consists of six subsystems as described below.

6.10.17.1 Temperature and Humidity Control (THC)

The ECLSS Temperature and Humidity Control subsystem (THC) circulates air through the HAB Module to provide adequate ventilation for the crew's comfort and cools and dehumidifies a portion of the circulating air to maintain the module temperature and the dew point within the prescribed comfort range. The THC provides a separate avionics air cooling loop to remove sensible heat generated by electronic/electrical devices in equipment/experiment racks. The THC provides intermodule air supply and return to adjacent SS elements. The THC provides re-

frigerator/freezer storage in the HAB Module.

6.10.17.2 Atmosphere Control and Supply (ACS)

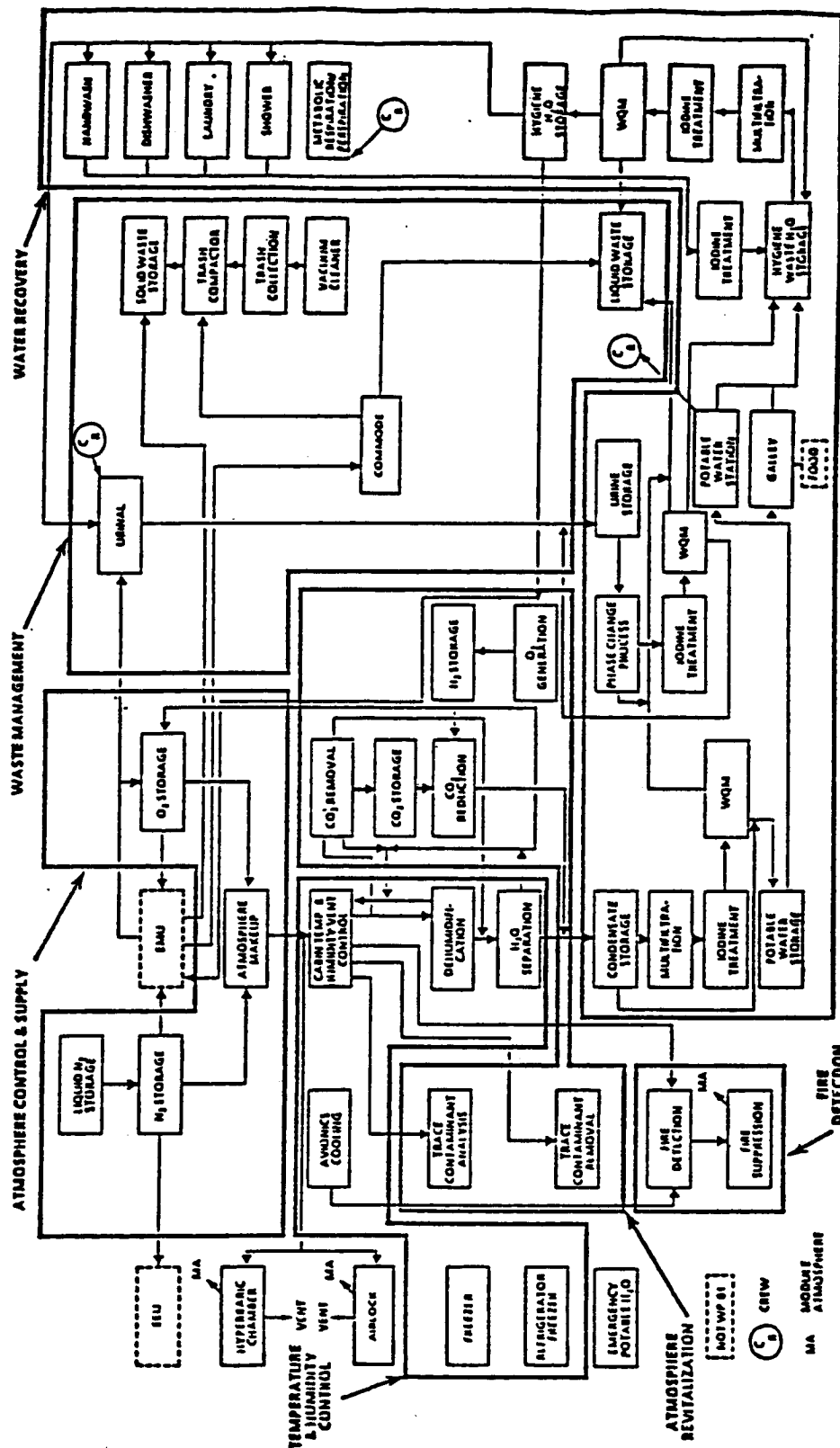
The Atmosphere Control and Supply subsystem (ACS) maintains the atmospheric total pressure and O₂ and N₂ partial pressures within the pressurized volume by adding appropriate gases from the stored N₂ and stored or generated O₂. Excess pressure in the module is relieved by venting through pressure equalization valves to adjacent modules, or is vented to space.

6.10.17.3 Atmosphere Revitalization Subsystem (AR)

The Atmospheric Revitalization subsystem (AR) processes a portion of the circulating air in the HAB Module for cooling and dehumidification to remove excess CO₂ produced metabolically by the crew. Excess water is electrolyzed to generate O₂ to replace that consumed by the crew. H₂ produced as a by-product of the electrolysis is used to reduce the CO₂ to carbon and water. This water replaces the water from other sources used in the electrolysis unit to effectively close the CO₂/O₂ loop. Trace contaminants released into the atmosphere from a variety of sources are removed by filters and catalytic reactors in the AR.

6.10.17.4 Water Recovery and Management Subsystem (WRM)

The Water Recovery and Management Subsystem (WRM) processes humidity condensate from the THC and water produced in the reduction of CO₂ in the AR in the HAB Module to provide potable water for crew consumption. Additional processors recover most of the water from



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FIGURE 6.10.17-1 ECLSS SCHEMATIC DIAGRAM

FIGURE 6.10.17-1 ECLSS SCHEMATIC DIAGRAM

the crew's urine and urine flush water and reclaims used hygiene waters. Both of these sources are used for hygiene uses and electrolysis to provide O₂. All waters are treated to prevent the formation of hazardous or objectionable products and are dosed with a biocide to prevent the growth of bacteria. Processed waters are monitored to ensure acceptable quality prior to use.

6.10.17.5 Waste Management Subsystem (WM)

The Waste Management Subsystem (WM) collects human metabolic wastes, wet trash from the galley, and dry trash from all sources; treats them to prevent decomposition and stores them for return to Earth in the Logistics System for ultimate disposal. Feces collected in the commodes

is stabilized and compressed or encapsulated for storage. Wet trash, such as food wastes, is treated, compacted, and packaged for storage.

6.10.17.6 Fire Detection and Suppression Subsystem (FDS)

The FDS provides fire detection sensors in each equipment rack and at selected locations within the THC ducting and module volume. Upon detection of a fire, visual and audible alarms are provided to the crew and the fire suppression system activated. The fire suppressant is supplied from a centralized tank through distribution lines to each rack. Portable extinguishers provide local suppression capability. Emergency breathing packs for the crew are located in the HAB Module.

7.0 OPERATIONS AND PLANNING

In this section will be a narrative summary of the operations and planning study effort. It will be covered in four parts 1) Prelaunch/Postlanding, 2) Orbital Operations Approach Planning, 3) Logistics and Resupply Approach Planning, and 4) On-orbit Maintenance Approach Planning.

7.1 Prelaunch and Postlanding

This section defines the ground processing plans for WP-01 (MSFC) Space Station elements at Kennedy Space Center (KSC). This processing includes prelaunch assembly, test, checkout, integration, and launch of the initial Space Station (SS) elements and payloads, as well as launch of the cyclical resupply elements.

The general philosophy for ground processing of WP-01 elements at KSC is defined in this plan, and key ground rules and assumptions are identified. The plan discusses overall processing requirements for site activation, support equipment, flight equipment, facilities, security, safety and customer interfaces.

7.1.1 Ground Operations

The primary objective of the ground operations processing is to ensure that the WP-01 elements are ready for delivery to orbit, and ready for assembly, integration, and use with Space Station elements already in orbit.

The prelaunch ground operations sequences will require verification of system level and element level functional integrity, as well as verification of interface operational integrity, between WP-01 elements and interfacing elements. The interfacing elements consist of: WP-01 element to orbiter, WP-01 element to launch facility, and WP-01 element to ground support facility, as applicable.

A general launch site test and operations flow is shown in Figure 7.1.1-1.

Complete outfitting of the U.S. Laboratory module and the Logistics Elements prior to delivery to the launch site is planned, and allows for minimal launch site processing and checkout activities. These activities include receiving/inspections, preps of internal equipment and supplies for launch, prelaunch configuration checks, and element-to-NSTS interface integrity verification.

- a. The U.S. Laboratory Module will undergo a stand alone system level test in the SSPF. Orbiter interface electrical testing will not be required, as the U.S. Laboratory will be quiescent during RSS PGHM, Orbiter, and launch processing.
- b. The Logistics Module will also undergo a stand alone system level test in the SSPF, and in addition, will require tests to verify power, telemetry, and thermal interfaces, in the SSPF, and in the Orbiter.
- c. The payload equipment which will be installed in the Logistics Module for transfer, on orbit, to a laboratory module, may be active at launch and may require power-up testing at KSC.

7.1.2 Top Level NASA Requirements

The following Prelaunch Operations Requirements were obtained from the SS Phase B RFP, Section C, Attachment C-3, Paragraph 2.3.

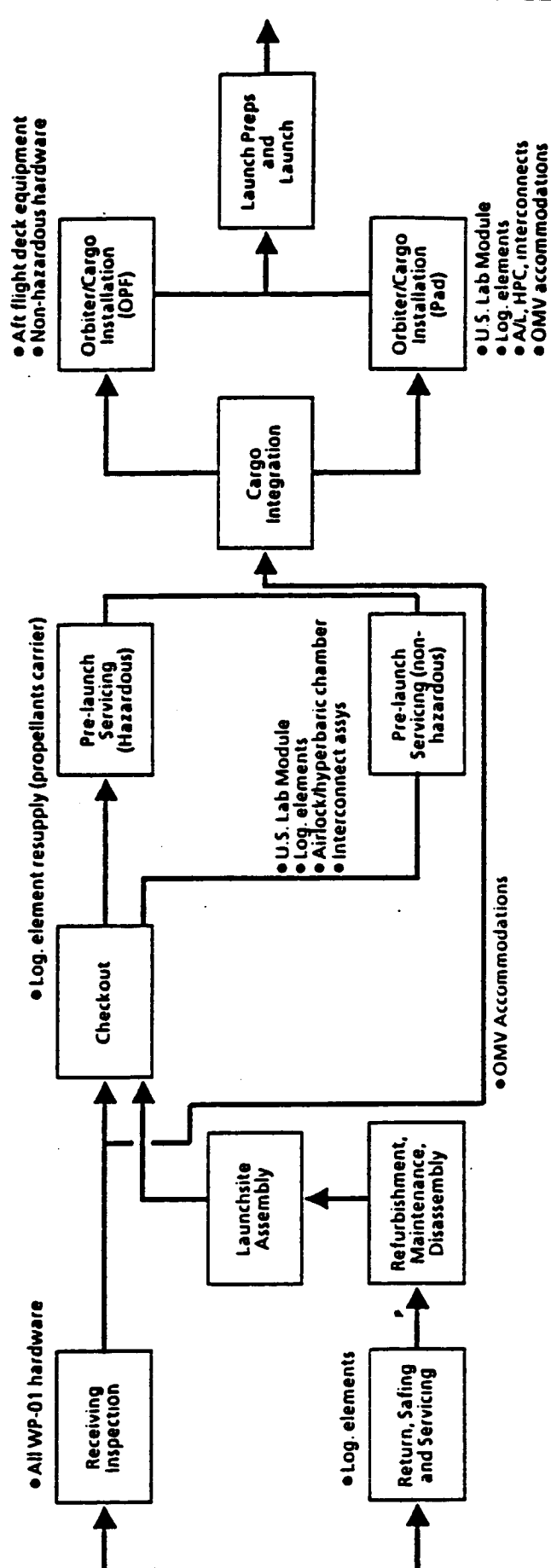


FIGURE 7.1.1-1 LAUNCH SITE TEST AND OPERATIONS FLOW

FIGURE 7.1.1-1 LAUNCH SITE TEST AND OPERATIONS FLOW

The Space Station Program will employ a number of practices designed to reduce the cost of developing space hardware. To ensure that program costs are minimized, it is assumed that the practice of protoflighting will be employed to reduce test article costs.

Operational requirements for initial elements processing and for resupply activity, in preparation for delivery to orbit, are:

- a. Prelaunch operations shall provide for cost-effective processing of all elements and payloads and for verification that their respective systems are launch ready.
- b. Maximum use shall be made of flight system capability to reduce the requirements for Ground Support Equipment (GSE) and other support during ground testing.
- c. Physical and functional interfaces between each Space Station element, subsystem, component, between payloads, the NSTS, and the Space Station shall be demonstrated as compatible and functional before being committed to launch.
- d. A program capability shall be provided to ensure that all modifications and upgrades function properly and are compatible with interfacing hardware and software components.
- e. The Space Station equipment and facilities required for an NSTS rescue mission shall be configurable to a launch readiness state within 19 days of notification.

- f. Flight element design shall not preclude its horizontal and vertical installation into, and removal from, the Orbiter; nor shall it preclude late launch pad access.
- g. The capability to service and deservice consumables within the flight element and to deservice waste and refuse shall be provided.

The following general assumptions are made:

- a. Space Station elements are assumed to be fully assembled and acceptance tested at the manufacturer's facility. Any extra services required at the launch site, will be analyzed and adjustments made accordingly.
- b. The basic SS modules are assumed to have been designed to be best accommodated by horizontal processing, with installation in the NSTS vertically at the launch pad; however, capability to install/remove vertically or horizontally shall exist.
- c. The following KSC facility capabilities are assumed:
 - A facility to accommodate non-hazardous ground processing of Space Station elements, Space Station resupply and Space Station payloads.
 - A facility capability for cryogenic testing and processing of OMV components.
 - A processing facility to perform hazardous operations on Space Station

propellant resupply tankage, OMV related tankers, and hazardous portions of the Logistics Elements.

- d. Use of proven design center or supplier assembly and test procedures, programs, GSE and personnel will be made for launch site operations to the maximum extent possible.

The following WP-01 related assumptions are made:

- a. The U.S. Laboratory Module and Logistics Elements will be processed horizontally in the SSPF and installed vertically in the Orbiter at the pad.
- b. The Logistics Elements will be removed horizontally at the Orbiter Processing Facility (OPF) on return flights.
- c. The U.S. Laboratory has no requirement for cryogenic or hazardous propellant servicing.
- d. The U.S. Laboratory payload/experiment equipment will be installed and integrated into the module at MSFC.
- e. The U.S. Laboratory launch configuration has no requirement for orbiter services. The lab will be quiescent at launch and will be activated during Space Station on-orbit installation and integration.
- f. The Logistic Module launch configuration will require data, power and thermal interfaces with the Orbiter.

7.1.3 Verification Requirements

The WP-01 Requirements are listed below.

7.1.3.1 General Verification Requirements

The following requirements apply to all Space Station flight elements, associated GSE, and facility processing at KSC during the initial operations phase and the follow-on operations phase:

- a. Space Station system verification shall demonstrate that the performance of the SS subsystems, elements, payloads, and GSE meet established requirements and that the related interfaces are compatible and functional.
- b. Final assembly, integration and demonstration of capability will occur on-orbit and will never be fully demonstrated on the ground.
- c. Verifications will be at the lowest system, subsystem, assembly, or component level practical, to minimize costs.
- d. Interface simulators and master tooling will be used extensively for interface verifications.
- e. Before beginning flight element processing, proper operation of all facility services and GSE (to be used in processing the flight element) shall be verified.
- f. Procedures, techniques, software, and capabilities planned for use on-orbit shall be demonstrated and shall be used to the maximum extent possible for prelaunch verification of the SS elements.

- g. Safety critical hardware and interfaces shall be verified by ground tests whenever feasible.
- h. SS elements shall be installed horizontally or vertically in the NSTS Orbiter as late in the NSTS processing flow as feasible.
- i. SS hardware and software configurations and interfaces shall not be changed or disconnected subsequent to verification for launch unless absolutely necessary.

7.1.3.2 Flight Element Verification Requirements

The requirements listed below apply to element stand alone verification processing and integrated element verification processing at KSC. Where requirements are peculiar to the Initial Orbital Capability (IOC) or the PMC, they are so designated. Otherwise, the requirements are applicable for ground processing for both the Space Station IOC and PMC.

7.1.3.2.1 Basic Element Verifications

- a. Space Station modules shall be processed horizontally from arrival at KSC through element checkout.
- b. Upon delivery to KSC, a cost effective, minimum test program, commensurate with acceptable risk, will be conducted:
 - to demonstrate proper system performance following transportation
 - to provide assurance that the system will function after deployment in orbit

- c. element checkout/reverification at KSC shall use applicable sections of the same procedures, software and GSE used for element checkout at the element contractor's site.

7.1.3.2.2 Element-to-Payload Verifications

- a. Payload form, fit and functional integrity shall be verified by the integration contractor prior to delivery to KSC.
- b. For ground processing, payload testing after installation in an SS module shall normally be limited to that required to verify P/L-to-SS interface, and will be performed at the Contractor's facility.
- c. During PMC processing, payload-to-SS interfaces shall be verified, using simulators, before payload delivery to the orbiting SS.
- d. Payloads to be manifested in the Logistics Elements will be verified prior to shipment to KSC. Payloads that require an active interface (power, data, thermal, etc.) within the Logistics Elements, will be verified during Logistics Element Cargo Integration at KSC. Payloads that do not need an active interface, should not require any subsequent verifications.

7.1.3.2.3 Element-to-Orbiter Verifications

- a. SS Element-to-NSTS interface verification shall be performed (if re-

quired) after installation of the elements into the Orbiter Payload Bay.

- b. Functioning of the SS elements while in the Orbiter Payload Bay shall be limited to that required for the mission and SS Element-to-Orbiter interface verifications.
- c. Procedures and equipment developed for these interface verifications will reside at the launch site and will adequately demonstrate physical and functional interface capabilities.

7.1.3.2.4 Logistic Element Verifications

- a. Initial processing of Logistics Elements shall conform to the general initial processing of the other Space Station modules.
- b. Logistics provisions shall be stowed in the Logistics Elements off-line, as late as practical, before installation of the Logistics Elements into the Orbiter. Time critical items will be installed at the latest opportunity prior to launch.
- c. Upon return from orbit, the Logistics Elements shall be recovered from the Orbiter in the OPF and delivered to the appropriate processing facility where the returned cargo shall be removed and dispositioned.
- d. During Logistics Element turnaround processing, the Logistics Element systems will be reserviced, cleaned and reserviced as necessary, and the

integrity of the element shall be reverified, as required. Subsystem testing will be minimized with only testing of newly established interfaces. WP01 contractor will participate in this activity.

7.1.3.2.5 Modification/Upgrade Verifications

- a. All modifications and changes to the baseline hardware, software, and procedures shall be verified prior to their commitment for use.
- b. During IOC, processing, modifications and changes prior to launch of SS flight elements, hardware, and software shall be verified during ground processing of the affected element.
- c. During FOC, processing, proposed modifications and changes to on-orbit flight elements may be verified on the ground using SS element simulators, or identical SS elements that have not yet been delivered to orbit.

7.1.3.3 Requirements Documentation

The ground processing launch site test and retest requirements documentation system will be determined during Phase C/D.

7.1.3.4 Test Documentation

Maximum use will be made of contractor integrated procedures and element processing documentation, that have been verified by use at the WP-01 assembly and integration facility for KSC activities.

7.1.4 IOC Processing Concepts

7.1.4.1 Verification Approach

The verification approach taken for processing the IOC Space Station elements is based on operations to achieve maximum assurance of mission success consistent with a cost-effective processing of the elements, and verification that the respective systems are launch ready.

7.1.4.1.1 Ground Support Equipment and Facilities

Space Station facilities and GSE will be verified before first use processing of the flight elements. Handling equipment will be proof-tested; tools and test equipment will be calibrated and placed in a certification recall system. Facility power, liquids and gas supplies will be verified before connecting them to SS flight equipment or to GSE. Facility air-conditioning temperature, humidity, and filtration capability will be verified.

Element unique GSE will be delivered to KSC and installed in the appropriate facility. GSE-to-facility and GSE-to-Element interface verification tests will be performed prior to use in processing the flight elements.

NOTE: MGSE, EGSE, and FSE are defined in detail in WP01 End Item Support Equipment, DR02, dated October 31, 1986.

7.1.4.2 Operations Processing Team Concept

KSC will provide management, technical support and facilities for test, integration and launch of Space Station elements. The processing team will be composed of

NASA, KSC contractor personnel and WP-01 personnel.

Processing of the IOC Space Station elements will be the prime responsibility of the WP-01 personnel, supported by appropriate KSC personnel. The FOC and cyclical resupply processing will be processed in the same manner by a resident KSC processing team, with WP-01 supporting personnel.

Space Station WP-01 element checkout will be controlled from a test and monitor station other than the Launch Control Center (LCC). Space Station functions, when integrated with Orbiter activities performed at the OPF and Launch Pad, will be controlled from the Payload Console location in the Launch Control Center. The Space Station Element test conductor will provide the interface between the Space Station processing team and the Orbiter test conductor.

7.1.4.3 Standard Launch Site Operations

There are several operations to be performed during launch preparations of the Space Station elements that are common to all of the individual element processing flows. These operations are described in the following paragraphs as standard processing tasks.

7.1.4.3.1 Transportation

Space Station elements will be unloaded from their carrier vehicles at the KSC Shuttle Landing Facility or CCAFS Skid Strip (for air transported elements), at the KSC Turn Basin Facility (for barge transported cargo), and at Port Canaveral (for ship-carried cargo). Each SS Element, in its transportation container or fixture, will be loaded onto a suitable land transporter/

trailer and routed to the SSPF receiving area. Overland transported items will be routed directly to the SSPF receiving area.

7.1.4.3.2 Off-Site Transportation

Transportability is a key factor in early Space Station planning and must be factored into the development of Space Station element design. Transportation is considered a KSC responsibility.

7.1.4.3.3 Handling/Hoisting

Handling and hoisting operation of all major elements and support equipment will be performed using element unique handling GSE, same as, or equivalent to, the handling GSE used at the factory. A full complement of element unique GSE will accompany the flight hardware to the launch site. The standard KSC inventory of sling, cables, fixtures, and other handling/hoisting equipment will be used on an as-required basis. Refer to paragraph 7.4.1 for MGSE.

7.1.4.3.4 Receiving Inspections

All WP-01 Space Station hardware received at KSC will undergo a receiving inspection by WP-01 personnel, in conjunction with KSC personnel, to ensure an acceptable condition of the hardware and accompanying documentation.

7.1.4.3.5 Leak Checks

Leak checking will normally be done only in case the system level verification test indicates a pressure was below specified limits. Each of the pressurized modules will have a leak check performed if removal and replacement of a port, hatch, or closure plate is required.

7.1.4.3.6 Weight Checks and Center-of-Gravity (CG) Checks

Weight and CG checks will be made using load cells during the final hoisting of the elements into the Orbiter Payload Canister (OPC) for delivery to the Orbiter. Weight and CG checks must also be performed on the resupply Logistics Elements.

Weight Logs will be maintained on all items installed or removed from the elements after the weighing operations to permit an analytical determination of the final weight and CG.

7.1.4.3.7 Stowage and Closeout

Stowage of crew equipment and supplies as well as spare parts and expendables should be performed before the elements leave the checkout facility. All non-perishable items should be stowed, and racks and other containers inspected and closed out before leaving the checkout facility. Plans should be made to also perform time-critical stowage, if at all possible, prior to move to the pad.

There should be no planned access to the U.S. Laboratory Module at the pad. For the Logistics Module, some near-continuous power-up support is anticipated to maintain refrigerated and frozen items. Space Station portable GSE, as well as electrical power and thermal control from the Orbiter, will be used to maintain the modules after module installation into the Orbiter.

7.1.4.3.8 Element Installations into the Orbiter

WP-01 elements will be installed at the launch pad from inside the Orbiter payload Canister (OPC), by hoisting the OPC to the Payload Changeout Room, and transferring the elements into the Payload Ground Handling Mechanism (PGHM) the OPC will then be removed, and the SS elements will be installed into the Orbiter PLB using the PGHM.

Installation of SS elements at the pad will permit independent preparation and scheduling of NSTS Orbiter, and will allow cargo operations to be optimized with the greatest flexibility. However, Space Station mission-dependent panels and equipment may be installed in the Orbiter at the Orbiter Processing Facility (OPF), to permit ease of installation and earlier checkout.

7.1.5 Operational Phase Processing Concepts

7.1.5.1 Resupply Flow

The Logistics Element resupply flow, is shown in Figure 7.1.5.1-1. The Logistics Element Resupply Flow is also contained in Boeing document D483-50052-2, "Space Station" Prelaunch Operations Plan (DR-07).

7.1.5.2 Follow-On Element Processing

Growth of the Space Station will consist of processing and delivering additional habitat and laboratory modules to extend the basic station capabilities, including crew size, as well as adding totally new elements to provide a greater range of payload services. This section provides

processing concepts that are envisioned to apply to the follow-on phase of Space Station operations.

7.1.5.3 Additional Element Processing

The second, and any additional flight elements that are replicas of those launched for the IOC, will be processed through basically the same phases as the initial element. Some operations may be reduced in scope due to the maturity of experience with the hardware, software, procedures, and results of the on-orbit performance record of the first element of each type.

The use of standard interface mating hardware, as well as the use of standardized functional interface characteristics, for electrical power, data, and fluids, will make ground verifications sufficient to provide assurance of on-orbit success.

The use of proven procedures, facilities, support equipment, and an experienced processing team will enhance the efficiency of preparing the second and follow-on elements, so that a reduction in time and overall cost can be expected.

7.1.5.4 OMV Accommodations

The growth option for the Space Station calls for extension of the OMV hangar facility and the supporting structure, as well as for the addition of a new OMV facility.

The processing flow for the new OMV facility will be the same as that for IOC; however, system and subsystem testing may be performed at a higher level if on-orbit operations have shown that the elements have performed as expected in space. In addition, experience in handling these elements will reduce processing operations time.

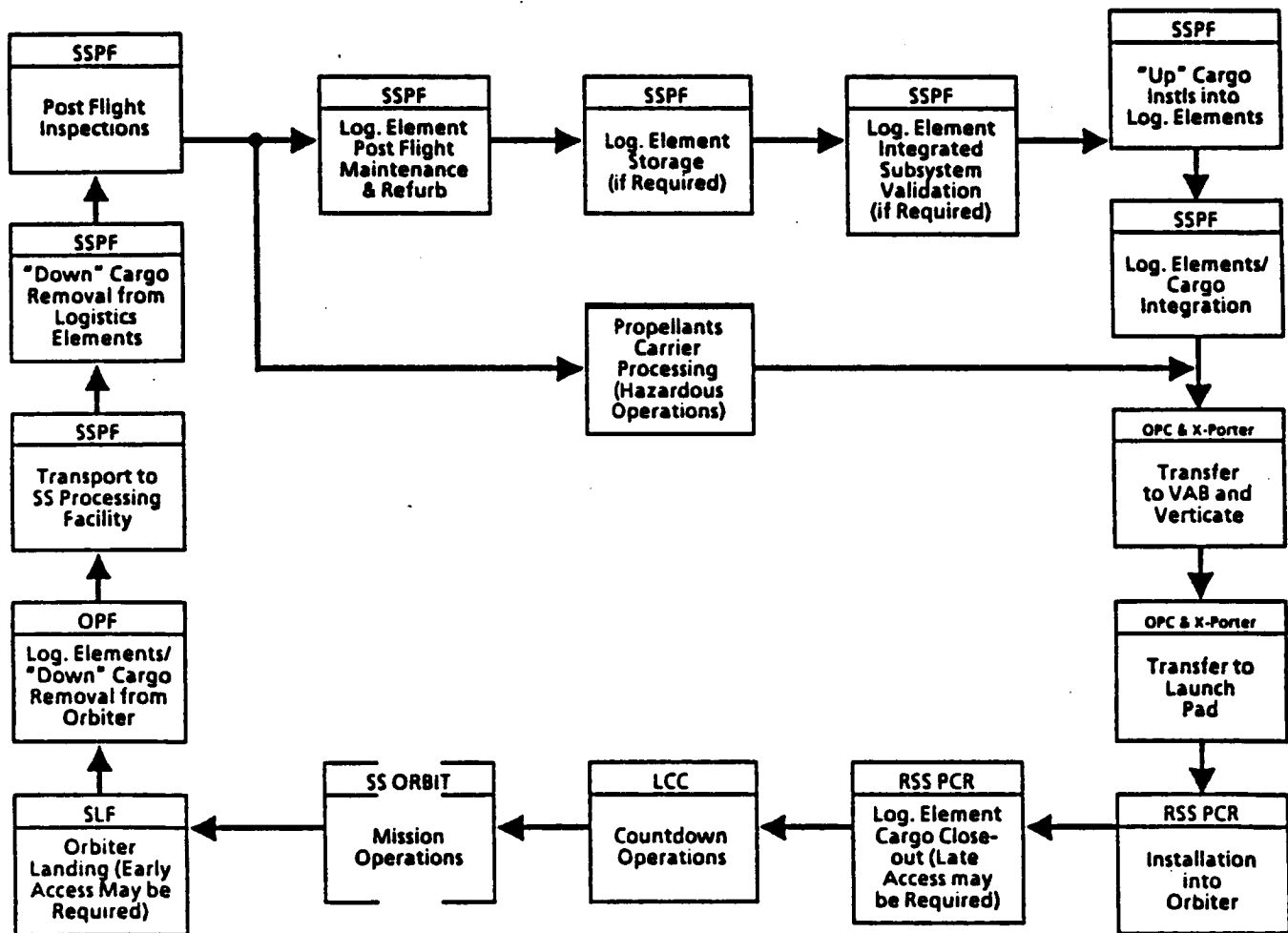


FIGURE 7.1.5.1-1 LOGISTICS ELEMENT RESUPPLY FLOW

7.1.5.5 Maintenance, Refurbishment, and Reconfiguration

Maintenance, refurbishment and reconfiguration of Space Station flight hardware is baselined to be performed on orbit, or to be returned to ground based service facilities on infrequent intervals. Space Station WP-01 hardware that has been returned from orbit because of failure will be analyzed to determine the causes of failure and what appropriate action needs to be taken to prevent recurrence of the failure.

Some items of Space Station WP-01 hardware expected to be returned on a routine basis for maintenance and refurbishment, are the Logistics Elements propellant tanks. The propellant tanks will be refurbished and retested in the Hazardous Processing Facility (HPF) and in the cryogenic test facility, as applicable. Additional items will be refurbished either at the launch site or at depot maintenance facilities.

7.1.6 Ground Support Requirements

7.1.6.1 Facility Requirements

Space Station System elements will require a variety of ground processing facilities. A summary of general ground processing requirements imposed upon all Space Station ground processing facilities are:

- a. Sufficient size, space, and room height for element horizontal processing, handling, lifting, assembly, access, loading.
- b. Standard utilities; such as electricity, phones, water, fire protection, compressed air, GN₂, vacuum, etc.
- c. Environmental Controls

- Cleanliness: Class 100,000 (at conditioned air, filter outlets)
 - Temperature: 680-770F
 - Humidity: 40%-50% R.H.
- d. Support areas for office space, logistics, payloads, shops, and labs.

7.1.6.2 GSE Requirements

Requirements for GSE are identified from the various processing scenarios, ground processing test phases, and ground operational requirements, for the Space Station flight hardware.

WP-01 End Item Support Equipment including MGSE, EGSE, and FSE, descriptions and requirements are found in DR-02, dated October 31, 1986.

- a. Access GSE such as Portable work stands and access equipment will be required to provide access to all exterior areas of the various elements and integrated/palletized cargo, both in the horizontal position in the processing facility, and for vertical access at the pad (PCR/Orbiter). Ingress/egress access equipment and 1G internal flooring for each module will be required for horizontal processing, and contingency vertical-access equipment will be required for late pad access to the module interiors.
- b. Handling GSE will be required for lifting modules, major elements, subsystems, ORU's and GSE. Pallets and tugs can be used for movement of Space Station elements within the facilities. Overhead cranes and strongbacks, will be required to in-

stall Space Station elements and integrated cargo into the Orbiter Payload Canister (OPC) at the SSPF and to remove Space Station hardware from shipping containers. Various standard lifting devices such as forklifts, and portable cranes, slings, and cables will be required for auxiliary lifting, handling, and assembly of heavy hardware.

In addition, the Logistics Elements will require external and internal provisions for installing/removing, and handling outfitted payload/experiment racks, resupply racks, and stowage racks.

- c. Protective Equipment will be required for all surfaces and hardware subject to scratches, tears, punctures, or impact damage. This also includes contamination covers for surfaces such as heat transfer assemblies, windows, multilayer insulation (MLI) and hatch sealing surfaces.
- d. Mechanical Simulators will be required for simulation of SS-to-SS and SS-to-Orbiter, mechanical system interfaces during test, refurbishment and maintenance configurations. Included are element functional simulators (liquids and gases), and if required, berthing simulators.
- e. Ground air conditioning units are required for avionics cooling and for personnel comfort, internal to the elements, during ground checkout operations.
- f. Specialized GSE such as tilt frame dollies, window holding fixtures, hatch seal surface protectors, rack dolly, and airflow balancing equipment will be required for KSC processing (see Appendix E of reference document gg, Appendix A, for a more complete list).
- g. Electrical Simulators will be required for simulation of SS-to-SS, and SS-to-Orbiter interfaces during test, refurbishment and maintenance verification. Equipment to simulate individual element interfaces (i.e., power, SSIS, audio/video, etc.) will be required during certain testing. Power sources will be required to simulate power from the solar array and/or power distribution systems.
- h. Ground Data Management System (GDMS) capabilities are still to be assessed. Interfaces between KSC facilities and SS Element GSE items will be defined during Phase C/D.
- i. General Purpose Test Equipment (GPTE) will be required for normal and contingency operations. It is assumed that a Space Station dedicated loan pool will provide standard test equipment such as ohmmeters, oscilloscopes, digital voltmeters, and strip chart recorders that would be shared between all SS program users.
- j. Voice Communications will utilize the KSC standard Operational Intercomm System(OIS), which should be available at all SS support facilities.

7.1.6.3 GSE Implementation Approach

The following ground rules and guidelines will be followed for implementation of the GSE requirements, with the goals of reducing redundant hardware, increasing commonality of parts, reducing the number of GSE units required, and reducing O&M requirements.

GSE requirements will be documented using a system that will adhere to the following guidelines:

- a. Duplication of hardware will be minimized.
- b. GSE will be minimized through maximum use of on-board systems for test and checkout.
- c. GSE performing similar functions (including hardware, software, documentation, and procedures) will be shared.
- d. Standard interfaces will be established between replaceable units.
- e. Database standards will be defined so that identical data base elements can be used.
- f. If technically and economically feasible, computer controlled scanning equipment will be used to verify physical interface compatibilities of SS elements, sub-elements, and payload hardware, without requiring mechanical moves and mating operations.

7.1.6.4 Logistics Support Requirements

The transporting of supplies to the SS crew every 12-weeks will require the following logistics support:

- a. Preparation and packaging of food to be loaded into the Logistics Module's freezer and storage container.
- b. A facility freezer to store food at KSC, with the capacity large enough to store food for several resupply missions.
- c. Capability to service, inspect, and fill the potable water tanks, oxygen tanks, nitrogen tanks, and other tanks (when identified), in place, without removing the tanks from their carriers.
- d. Capability to store, process, recycle, and dispose of CO₂ removal chemicals.
- e. Packaging and storage of any personal hygiene equipment.
- f. Packing and storage of crew clothing.
- g. Metabolic waste disposal

The transporting of Space Station and payload supplies every 12-weeks demands the following support:

- a. Storage, prepackaging, and control of the Space Station consumables (lights, filters, tools, and test equipment).
- b. Development of a computerized inventory system, with associated software, to establish and maintain Space Station payload supply requirements and spares requirements, as well as GSE spares.
- c. Storage, packaging, and control of all Space Station, OMV, and payload

spares, as well as ground equipment spares.

- d. Storage, maintenance, and control of Laboratory Module experiments.
- e. Storage, maintenance and control of trunks for Logistics Elements special items and special carriers.

7.1.7 Customer Interfaces

The Space Station is to supply required services to potential customers for the operation of payloads in a stable, controlled environment. The payload integration process becomes a task of ensuring that all physical, command, data, safety, and inter-payload incompatibility issues are resolved. Payload design reliability, and probability of success, are the sole responsibility of the individual payload organization.

The Space Station program will identify to prospective payload groups, in the form of an interface document, the physical interfaces requirements (rack dimensions, standard connections and attach points), and safety requirements (acceptable materials, processes, and fire suppression techniques), along with the command and data interface parameters.

NASA will also describe the associated cost for each service or combination of services. The customer can then select the appropriate services for their payload and enter into a written agreement with the Space Station program that specifies the contractual responsibilities for each group. Costs associated with providing services to the payloads should be the responsibility of the customer, as long as the Space Station provides the agreed-to services.

To facilitate customer communication and payload integration, a single Space Station

Integration Group should be established. This integration group would be responsible for the entire payload integration process, from initial customer contact, through on-orbit installation, activation, operation, shut-down, and post-mission retrieval. With a single NASA integration organization providing the customer interface, a complex integration process can be minimized. Compatibility issues, between payloads, and competition for Space Station resources, will be resolved by the Space Station integration office and the affected payloads representatives.

Payloads destined for operation on the Space Station (and not while aboard the orbiter), only have to be integrated into one of the Logistics Elements rather than onto the Orbiter. This integration scheme allows for a smoother interface between potential customers and the Space Station integration office. Integration of the Logistics Elements into the Orbiter is a responsibility of the Space Station Logistics Group.

The customer payload integration processing has the potential for being the greatest source of customer security problems. Security considerations/concerns/problems must be negotiated with NASA on a case-by-case basis.

To limit customer security risks, the exchange of proprietary information between the customer and NASA Space Station integration group should be limited to areas of safety, test, and physical interface verification, however, non-proprietary information from the customer, must list all materials & processes involved with payload during the mission, to ensure that all safety requirements are met (toxins, explosives, etc.). The integration of customer data/command security procedures

and accommodations, other than the physical security provided by the SSSC,

will be the responsibility of the payload customer.

The above plans remove much of the complexity currently experienced in customer payload integration activities, by placing the design, test, and verification process within the control and responsibility of the individual payload groups. The pre-mission verification process also becomes the customers responsibility.

7.1.8 Safety and Security

7.1.8.1 Safety

A ground operations safety program will be implemented by KSC for the Space Station Program to prevent injury to personnel and to preclude damage to SS flight hardware, processing hardware, payloads, and associated GSE.

The SS element contractor will develop a Safety Plan for WP-01 operations at KSC in compliance with applicable KSC Safety Documents. The Safety Plan will become a part of the Existing D483-50075-1 "WP-01 Safety Plan."

The SS element contractor will furnish the a detailed safety plan for Level C approval. This plan will describe the contractor's safety program and will present the approach for implementing the KSC safety requirements for which the contractor is responsible. The safety plan will address areas of personnel safety, equipment and material safety, safety management, system safety, industrial safety, and test operations safety. The plan will be approved by KSC Safety Office prior to start of WP-01 hardware processing at KSC.

7.1.8.2 Security

Security plans and procedures will be instituted that will protect SS elements from damage and will protect Government classified and private proprietary information from unauthorized disclosure or compromise.

An integrated Space Station security plan will be developed by NASA/KSC that will deal with identified threats and vulnerabilities of the Space Station ground operations systems. Security planning will address three areas: resource protection, protection of classified information, and protection of customer and company sensitive (proprietary) information.

Prior to developing specific security system plans, a NASA study will be conducted to determine which items in each of the categories listed below must be protected. This can be done through analysis of the command and data and hardware elements that make up the Space Station and its ground support system. The extent of protection will be consistent with the security protection needs and the identified threats and vulnerabilities of the elements or systems involved.

- a. National Security Information
- b. Resource Protection
- c. Proprietary Information

When encryption or other measures are required for protection of proprietary information, such measures are the responsibility of the customer.

7.2 Orbital Operations Approach Planning

This section defines orbital operational functions for the Space Station and describes the related ground and crew functions, interfaces, roles, responsibilities, scenarios, and required support systems for the Space Station assembly operations and IOC operations. The preliminary on-orbit operations concept of WP-01, man-tended option concept, is described as well as the on-orbit operations plan for the preliminary growth version of the Space Station. Candidates for automation and autonomy applications to Space Station operations are also discussed. The approach optimizes Space Station operability by efficient utilization of the crew and ground support personnel.

The operations for on-orbit assembly, orbital outfitting of the modules, station shakedown and verification and IOC operations are provided. Included are the operations for the initial and cyclical resupply elements.

7.2.1 Assembly Phase

Conceptual planning for the SSP has progressed to the point that preliminary analysis of flight planning for the station assembly and implementation has begun. Because on NSTS cargo delivery capabilities, multiple missions are necessary to transport the flight elements to orbit and to complete the station assembly and outfitting functions. The NSTS program currently provides the mission planning and analysis for the NSTS to deliver cargos to NASA-user agreed to requirements. The NSTS has the capability to provided the mission planning and trajectory development for the initial station assembly and resupply cargo flights with some increased efficiency. However, the low level detail planning and development of operational

flows and sequences, equipment packaging, special tool analysis and timeline estimating are new and complex tasks that cannot be readily separated from the basic SSP module and equipment design and development.

When all the elements defined as a part of an initial operating configuration are considered. The Space Station assembly phase extends over a period of years.

During this period the Space Station must pass through several sub-phases:

- a. A ground controlled space vehicle
- b. Orbital laboratory capable of limited initial experiment operations.
- c. A man-tended Space Station supporting payloads, satellite repair and science.
- d. A pre-IOC permanently manned configuration with a specialized checkout crew complement.
- e. A full up configuration, including operations crew.

7.2.1.1 Assembly Sequence

The Space Station assembly sequence begins with the arrival of the first Space Station elements at the assembly orbit. The assembly sequence will be completed when the elements have been assembled and the station can be permanently manned and its systems are capable of supporting the crew until the next normal resupply mission. Recommendations on an optimum assembly altitude and an optimum launch sequence can be made considering the National Space Transportation System (NSTS) capabilities.

The assembly altitude, launch sequence, operations planning activation and checkout, manning profile, automation requirements, and assembly-unique operations for the current Space Station concept are discussed in the following paragraphs.

NOTE: This section has not been updated per Critical Evaluation Task Force (CETF).

7.2.1.2 Assembly Altitude Profile

The assembly sequence developed minimizes the drag on the Space Station during assembly. This is achieved by several innovations. On assembly missions one through three, the assembly is flown in a flight direction parallel to the center transverse boom. This provides a minimum profile for drag. After mission four, the flight path is rotated perpendicularly to the transverse boom to provide necessary power from the solar power elements to run limited scientific experimentation in the Manufacturing and Technology Laboratory. The power and station radiators and the solar power modules are installed in two parts with the last part being deferred to a point that full thermal radiation and electrical power are needed. Deferring these elements reduces the drag profile. In addition, the photo voltaic configuration solar panels should be designed to be partially deployed for electrical power as needed to reduce drag.

Calculations were made to establish configuration ballistic coefficients for each step of the assembly sequence. The nominal case and 2 sigma atmospheric conditions from the JACCHIA 1970 Atmospheric model were used to predict the necessary initial deployment and reboost altitude to allow orbital altitude decay to 407.44 KM (220nm) for the next assembly rendezvous at a 45 day interval.

7.2.1.3 Launch Sequence

The proposed launch sequence discussed was developed to meet the following requirements:

- a. NSTS assembly flights will be launched from Kennedy Space Center (KSC) and will place the Space Station in a 0.5 rad (28.45 degree) inclination orbit.
- b. Mission profiles will be used for assembly which result in NSTS rendezvous with the Space Station on the first crew day, but berthing/docking occurs after a crew rest period. Therefore, two days elapse from launch to on station IVA.
- c. The ground will be prime for command and control of the assembly process. Both NSTS and ground command and telemetry will be provided for the checkout, activation and monitoring of critical components prior to, during and after deployment and/or assembly. Until the TDRS capability is operative, the data rate will not support video transmissions.
- d. Full FL will be berthed to the station and activated before the spent LM is detached and stowed in the orbiter for return.
- e. Assembly sequences that are dependent upon the simultaneous presence of more than one orbiter shall not be considered.
- f. The docking module should be considered as part of the orbiter pay-

load, and installation of the module on the station with orbiter modifications should be considered as an option only.

- g. Orbiter lift capabilities to the various altitudes will be according to Payload Integration Plan (PIP), JSC 18508, values. The orbiter lift capability of 17,347.93 kg (38245 pounds) to 500.04 km (270 nm) plus 45.36 kg/km (100 pounds/nm) for each nm under 500.04 km (270 nm) was used for preliminary planning purposes.
- h. NSTS performance enhancements per NASA technical directive JJ20039 will be considered consistent with the other groundrules. Consider enhancements for two flights per year.
 - (1) assume an additional 1102.3 kg (5000 pounds) orbiter lift capability for assembly analysis involving use of 109% orbiter main engines.
 - (2) assume payload penalty of 1814.4 kg (4000 pounds) for flights requiring docking/berthing mechanism.
- i. For first flight manifesting, Orbital Maneuvering System (OMS) rendezvous propellant should be offloaded.
- j. For assembly flight planning all NSTS flights will be dedicated flights.
- k. A power source will be provided from the initial flight on, to support the on-orbit assembly operations and the activation and verification of functional capabilities.

- l. In order to reduce aerodynamic drag, the power system shall be capable of being flown in a minimum drag position yet still produce power.
- m. The resulting configuration following each assembly flight will have the necessary resources, capabilities and redundancy to support safe operations between NSTS flights and to enable the next step in the assembly sequence for both nominal and contingency NSTS launch condition.

The proposed assembly sequence discussed was developed within the following groundrules and constraints:

- n. An Reaction Control Systems (RCS) capability will be established as soon as possible to provide both backup attitude control to the CMGs and reboost capability.
- o. The assembly altitude will be at a planned minimum altitude of 407.44 km (220 nm).
- p. Reboost will be planned to provide an orbital life time (to loss of control of the partially assembled station) of a minimum of 90 days.
- q. MSCS will not be used until station RCS is available for CMG attitude control backup.
- r. The Space Station will maintain attitude control during assembly.
- s. The International Space Station (ISS) configuration includes a dual beam, two U.S. modules (MTL & HSO) with nodes and tunnels (intercon-

nects) and the JEM & ESA elements defined as IOC Prime.

- t. NSTS turnaround and launch rate during the assembly phase shall be an average of one orbiter flight every 45 days (equivalent to a 9 orbiter flights per year for all Space Station flights). A minimum of 21 days between flights is available but will not increase the average rate of 9 per year.
- u. Assembly flights will utilize standardized NSTS flight designs, capabilities, and services to the maximum possible extent (e.g., common orbiter vehicle ascent profiles, flight support equipment, payload bay configuration, etc.). Development of Space Station program unique flight support equipment should be studied as an option only.
- v. The assembly sequence should demonstrate an early and progressive capability of accommodating user requirements, however, user accommodation will not result in compromising assembly operations.

The proposed assembly sequence discussed was developed using the following assumptions:

- w. The MSC will be capable of grappling into the orbiter bay and will have sufficient length/mobility to reach required locations for assembly. The MSC will be available starting with the third flight.
- x. Mass properties used are contractor generated data.

- y. Structure is a five meter (16.4 feet) erectable cell that is stowed by piece parts in the orbiter payload bay.
- z. Any violation of the NSTS cg envelope published in Volume XIV of JSC 07700 series documents can be arbitrated on an individual basis.
- aa. The propulsion system is designed with enough modularity to provide a limited reboost capability before the total system is installed, and is capable of being relocated during the assembly sequence.
- bb. Orbital outfitting will be accomplished by logistics flights as a transfer mode carrying common racks of outfitting equipment.
- cc. The maximum of 48 hours of EVA permitted is sufficient to support EVA requirements to assemble station structure, power production elements, and radiator panels prior to permanent manning.

7.2.1.4 Assembly Operations Planning

Operations planning for the Space Station Assembly Phase begins with an analysis of the mission and systems requirements. Flight scenarios are being developed for the WP-01 elements and used as a baseline for detailed functional requirements for Space Station assembly flight operations. In addition to defining the functional requirements for SS assembly and checkout payload integration with NSTS is required.

The initial integration activities include development of the Payload Integration Plan (PIP) for Space Station WP-01 elements. The PIP is the technical contract between

the Space Station WP-01 elements and the NSTS. It identifies all of the technical requirements for the integration and operations of the payload. In conjunction with the PIP, the development of the more detailed Interface Control Document (ICD) is required, and a flight compatibility assessment is conducted to evaluate the total payload and mission compatibility of the SS elements assigned to a particular flight. This activity culminates in a Cargo Integration Review (CIR) at approximately launch minus nine months. Subsequent to the CIR, the NSTS flight-specific products are generated.

PIP annexes which are subservient to the PIP and ICD are prepared to document the detailed information required by the NSTS to configure the Flight and Ground Systems necessary to support the Assembly Sequence missions. The number of annexes required is dependent on the details of a particular Space Station element. Typically, the PIP annexes are:

1. Payload Data Package
2. Flight Planning
3. Flight Operations Support
4. Command and Data
5. Payload Operations Control Center
6. Orbiter Crew Compartment
7. Training
8. Launch Site Support Plan
9. Interface Verification
10. (Reserved)
11. Extravehicular Activity

Based on the requirements detailed in the PIP and its annexes, the NSTS will develop a basic version of all the tools used

for training and for the execution of the flight. This includes all crew procedures, crew activity plan, and the mission rules.

The Payload Operations Working Groups (POWG's) are used to review the NSTS/Payload requirements and to resolve any issues during the development process. The POWG will consist of representatives from NSTS, WP-01, and any other work packages manifested for that mission. These basic products are reviewed at the Flight Operations Review, typically scheduled three months prior to launch. Any changes will be reflected in the final set of operations products, which are used for that flight.

7.2.1.5 Activation and Checkout

The on-orbit verification of the functional operations capability of the Space Station can be broken into four phases. The first two phases (station build-up and activation and on-orbit shakedown and verification) are the subjects of this paragraph.

Each launch transported a set of Space Station elements to orbit that were removed from the orbiter cargo bay, installed on the existing station elements (after the first flight), have their mechanical and unpowered features verified. Outfitting design must keep the outfitting equipment in a rack configuration as much as possible.

The manpower for the on-orbit shakedown and verification will be provided, in the main, by the Space Station crew that is in residence after the station can accommodate them. This phase of verification may be accomplished concurrently with the early station operational functions, e.g., when the first station supported EVA is planned, the appropriate verification procedures for that part of proximity operations can be accomplished.

Finally, some of the crew's time will be devoted to performing scientific experimentation after flight five. The Space Station will then have a partially outfitted Manufacturing Technology Laboratory, power, thermal control system and available NSTS crew support.

In summary, the manning profile assumes 7 personnel for 12 days with flight 9 through 12 being supplemented by the resident Space Station crew.

7.2.1.6 Automation Requirements

The Space Station buildup will benefit from automation assistance to human crew procedures. The automation requirements for WP-01 assembly will be consistent with the levels of automation to be incorporated at IOC. The current concept does not call for any unique automation devices/techniques for the assembly phase.

7.2.1.7 General Structure

The Space Station Program selection of erectable structures will require some special support equipment. Where special equipment is identified, it, in turn, has special functional requirements. This equipment may have to be assembled, positioned, set up, controlled, monitored, serviced and maintained with specially-trained personnel or servicer equipment located at the construction site.

7.2.1.8 MSCS

The Mobile Service Center (MSC) is a multipurpose device outfitted with a space arm. It plays an important function in the buildup of the Space Station and is a primary tool on the station to transport modules and/or payloads from the Shuttle cargo bay and position them for attachment to the Space Station truss structure.

The combination of MSC and EVA astronaut is utilized in locating, latching and erecting the structure segments. The same procedure is repeated for the radiators, the keel extensions and the lower boom. A major feature anticipated of the MSC is the "cherry picker" mode. Astronauts in EVA suits are positioned within their work envelope by the movable arms. Control of the arms and all features of the MSC resides with the EVA astronaut(s). The two arms can be used in several different locations on the MSC. This capability greatly expands the work volume of the astronauts.

The MSC will have a self-contained, rechargeable power supply. Depending on the work and the mission, the platform will be adaptable in terms of special storing devices and cradles for miscellaneous hardware.

An alternative to human support will be dexterous manipulator for the MSC arm. This system has the design goal of being equivalent to the capabilities of man, yet reduces the amount of support equipment and preparatory work.

7.2.1.9 Assembly-Unique Operations

Most of the initial assembly operations for the Space Station will be unique. The operations will initially occur from the Shuttle Orbiter and later from the available Space Station elements in conjunction with the Orbiter. Ground control will be the primary management authority for the assembly process, providing most of the monitoring, checkout, verification, and technical guidance. The on-orbit crew will provide control of the assembly process. These functions differ significantly from previous manned space activities and the post assembly operations described in this operations plan.

7.2.2 IOC Phase Ground Support Operations

This section provides a conceptual description of the operational functions to be performed by the ground elements in support of the Space Station during the IOC timeframe. Emphasis is placed on the roles and responsibilities, interfaces, and ground support daily activities.

The concept includes the following features: a streamlined approach to customer payload operation and the extensive use of software routine to reduce ground crew workload.

7.2.2.1 Ground Support Complex

The Space Station will interface with its ground support system primarily through the Space Station Support Center (SSSC) and various Payload Operation Control Centers (POCC). Operations and control of the station systems and subsystems will reside with the SSSC while users will operate via remotely networked POCCs. These POCCs operate under geographical functional control centers, (e.g., MSFC's MTL Operations Support Center (OSC), and OMV Control Center, GSFC's Platform Control Center (PCC), JEM's Tsukuba Central Operations, and ESA's Central User Facility. While recognizing the necessity for communications and limited data flow between these two facilities, they will operate as autonomously as possible. The capabilities of the initial ground support system will evolve as the station grows, including the ability to add remote POCCs as the need dictates.

Technical support of WP-01 subsystems will be provided at the SSSC. This resource will provide assistance in troubleshooting possible problems with subsystem hardware or in station monitoring/control as required. A telemetry link back to MSFC and/or WP-01 contractor

facilities will provide additional technical support and operations planning for the MTL on an as needed basis. Due to the automation anticipated systems monitoring, the manpower required for each time station support is expected to be less than for the STS.

POCCs will support and manage payload operations in a mode as transparent to the station as possible. A major POCC is foreseen for the manufacturing and technology laboratories with the capability of remote user support. Specific data will be through-put to user facilities, eliminating the need for extensive TDY and additional ground support equipment. User commands (non-critical) will be generated and formatted at the POCC for subsequent transmission to the station (or the SSSC if required by RF network constraints). All SSP centers will also interface via a coordination loop with audio, video and house-keeping data. Teleoperations will be performed for MTL experimental support from the ground.

7.2.2.2 Systems Monitoring and Control

The ground management of Space Station systems involves the monitoring, systems control, and malfunction and anomaly resolution when the station crew and automatic systems monitoring and control capabilities cannot adequately manage the system. The ground support complex will have systems management capabilities similar to those onboard the station, with the additional access to experts, test beds, and detailed knowledge bases for problems not resolvable onboard or more efficiently solved by a ground crew.

The SSSC will have systems management command and telemetry processing and control interfaces for all of the onboard monitoring and control systems. Individuals responsible for projected operations and support knowledge base will support

the ground monitoring and management of the Space Station systems. They will be managed at the SSSC and the information will be stored on board the Station for crew and other systems access.

A conceptual SSSC must have a complete data processing and display capability to support the on-line ground support team who may be the remote operators of the Space Station subsystems at a particular time; or they may be observing and acting as backup of an on-board Space Station crew; or they may be supporting a transient orbiter crew in an initial assembly and activation task or in a man-tended mode. The sequence of subsystem activation should prioritize getting the power and DMS on-line, then proceeding through reverification of the rest of the subsystems. Depending upon the "manned" mode in use, the SSSC must be manned to some level of surveillance at all times when a Space Station Crew is not on-board.

Communications and tracking systems data will also be available. Proximity and automated controlled approach data if, applicable, and status of other spacecraft during rendezvous and docking will be available. The SSSC crew will take control of the operation as a backup for Space Station control or in an unmanned SS condition. Attitude control and altitude control data will be displayed, including status of Attitude Control System (ACS) and reboost propulsion system. Appropriate safety systems alarms and status will be displayed identically in the SS and the SSSC. The ability to transfer control between the SS and the SSSC must exist at all times with appropriate software interlocks during certain critical operations. At other times, control would be established by Standard Operating Procedure (SOP), with primary control vested in the SS Director.

As much as possible, the SSSC will have identical display, controls, automated data systems, computer and data file access as the Space Station. If additional data capability is added in the SSSC, provisions will be segregated from the basic control and monitor equipment available in the station in order to stress identical control and management environments. Since the functional status of most, if not all, of the systems will be computer monitored for operation within limits by the on-board built-in self test capability and the DMS, the requirement for manned surveillance in the SS or the SSSC can be reduced significantly. Out-of-limits operation will be determined by the computer and an appropriate status or alarm signal generated to the SS or SSSC monitor, who can initiate corrective action.

7.2.2.3 Flight Design

The flight design function involves flight resources planning, maintenance planning, flight control planning and traffic management planning (proximity operations) for the Space Station, platform, OMV and interactions with the STS.

Flight resources planning includes planning for the use of Space Station, platforms, OMV, and payload in-flight systems, equipment and consumables. The SSSC will perform long term (monthly and weekly) Space Station platform and OMV resources planning and integrate the resources planning for the platform, OMV and payloads with the station resources planning. The SSSC planners may use a similar system to the onboard automated interactive flight resources planning system. The approved plan may be stored in the Mission Plans Knowledge Base for un-link to the Space Station version of the Mission Plans Knowledge Base. The Marshall Space Flight Center (MSFC) Operations Support Center will provide the flight

resources planning for use of the MTL and the MTL payloads.

The ground planners at MSFC will use the following knowledge base types as information sources and flight control planning:

- Systems Performance
- Operating Procedures
- Logistics
- Mission Plans
- Customer Unique Knowledge Bases

The flight resources planning function will iterate with the flight control planning, crew activity planning, maintenance planning and traffic management planning activities. The maintenance planning function, as part of the Maintenance Management Data System, is described in the On Orbit Maintenance Plan.

Flight control planning includes trajectory/flight dynamics design and planning, Guidance, Navigation and Control (GNC) planning, propulsion systems planning, ephemerides generation, star catalog maintenance, CG modeling and structural modeling for the Space Station, OMV, platform, Mobile Service Center System (MSCS), robots and EVAs. The SSSC planners perform the long term (monthly and weekly) flight control planning using the ground version of the onboard automated interactive flight control planning system. The approved flight control plans will be stored in a mission plans knowledge base for uplink to the Space Station when appropriate.

The flight control planning function will interact with the flight resource, traffic management and crew activity planning activities.

Traffic management planning is the integrated planning process for the control of spacecraft that will penetrate the Space Station traffic control safety zones. Traffic management planning requires coordination and exchange of data between the SSSC and other spacecraft control centers. It also involves interacting with the North American Air Defense Command (NORAD) for forecasting possible collisions and closest point of approaches to various space objects.

7.2.2.4 Operations Planning

The basic planning tool to be used in performance of operations planning is the mission and systems requirements analysis. The technique and engineering discipline will be used for flight operations analysis. Based upon the preliminary Flight Operations Plan JSC 30201, and other general program planning guidelines, generic flight operations scenarios for WP-01 flight elements will be developed. These scenarios then become generalized baseline flows from which the detailed set of functional requirements will evolve. The development of these flows is an iterative process as the program develops and design and operations guidelines become more firm. As successive versions are developed, they will be released in this document with a summary narrative outlining the overall plan scenario. A fallout of this analysis will be a definition of support equipment, software, procedures and manning requirements.

The operations planning function is used to verify the correct utilization of Space Station resources (power, thermal, station supplied common user equipment, crew availability, etc.) and to ensure coordination between ground and space activities. Three levels of planning will be used to ensure efficient resource utilization; long

term (monthly), short term (weekly), and daily planning cycles.

The long term and short term planning cycles are a ground function. During these two planning cycles conflicts between requested resources are identified and resolved. In addition, periods for payload operations that require coordination between the Space Station and ground POCCs, tracking, data processing facilities, etc are established.

The monthly and weekly planning cycles are used to produce a daily activity schedule. The daily schedule produced by the ground provides the crew with a skeleton activity plan that the crew must perform that day, along with the time constraints, required sequences, and other task constraints. The crew uses the ground provided plan to develop the detailed operations plan for that work day. The detailed crew work plan is then sent to the ground for coordination purposes.

Under the contingency conditions, the Ground Support Center become responsible for all planning activities in order to facilitate rapid flight crew resolution of the contingency. If the contingency includes a loss of communications are restored.

7.2.2.5 Procedures Management

Space Station procedures will be managed on the ground as part of the normal ground operations support function. The review and modification of the procedures will be a continuing effort over the life of the program. The ground will uplink required procedures to the Space Station for use by the onboard crew. The procedures stored at the station will be a subset of the total set of operational procedures. Procedures that are used infrequently will be transmitted to the station on an "as needed" basis.

All test and operations procedures used in conjunction with flight hardware processing and the interfacing ground support system will be maintained under engineering configuration control for hardware/software and documentation. As the hardware configuration becomes firm in released drawings and documentation, the procedures will be developed initially in a narrative/scenario format. They will then be converted to a computerized format maintained in the test monitor and control data base. An objective will be to automate all functional test and verification procedures and test sequencing. Maximum use will be made of the flight equipment built-in self test capability. The executive programs will sequence through a set of subroutines which may be called up, or deleted, as the test objected may require. If a procedure or software error is encountered, it will be documented on a procedure/software change notice as it is corrected. The PCN goes to Engineering to change the released record and the operation proceeds. The software in question will be electronically flagged to note the real-time change and contents in the operational records.

All procedures (preflight, flight operations and contingencies/emergency) would be integrated into this data file. This includes pertinent, other-contractor procedures interfacing into an integrated preflight or flight operation. As the Space Station program achieves IOC, the procedures for operational use will have transitioned from an assigned contractor-sustaining control and delivered into a fully-operational on-line NASA data system. Provisions must be made for availability on-orbit for both hard copy readout portability as well as screen display, as is appropriate for the activity being performed. For unusual EVA, a "procedure talker" on the audio/video net may be necessary for more complex operations.

7.2.2.6 Proximity Operations

Primary tracking and control responsibility resides on the Space Station during proximity operations with unmanned vehicles within the Space Station Command and Control Zones (CCZ). Ground functions during this phase of a mission re: back-up control, tracking for contingency operations, and performing independent checks for trajectory computations. Preflight planning for proximity operations would be performed on the ground and then transmitted to the Space Station.

A typical proximity operations mission would begin before the actual flight with detailed mission planning occurring on the ground. These would include trajectory analysis and contingency operations development which would include accommodation for possible unique instructions would be transmitted to the Space Station. When an arriving unmanned vehicle enters the Station CCZ ground phases control and tracking handover to the Space Station. During proximity operations where the Space Station has primary control, ground control will still have the capability to reacquire control for contingency operations. During proximity operations, if an approach is aborted, ground control reacquires control and plans another approach. During proximity operations, ground control acts as an independent check for trajectory computations. The ground would receive Global Positioning Satellite (GPS) positioning for both the Space Station and the incoming vehicle and compute relative trajectories.

7.2.2.7 STS Interface

The Space Station interface with the NSTS appears to be the normal user relationship with the transportation system over the long range. During the earlier SS implementation phase, a closer working rela-

tionship could prove beneficial. The SSP is unique in STS experience with respect to the concentration of multiple cargo flights to place the SSPEs on-orbit, followed by the detailed effort to assemble the station and activate it. This means that the flight crew/SS specialists will be performing new and different tasks than is normally performed with a new user. There will also be a number of "first time" unusual operations required.

Schedule integration and management during the post-IOC phase will be busy, but should be maintainable within the existing NASA scheduling system. The station schedules will interface with NSTS schedules and, as necessary, interface joint milestone commitment dates. If there is a great deal of interleaving of two flows of activity under separate agencies, special integrated schedules can be worked out jointly and maintained.

The Space Station interface to the STS, as any other user will be defined through the Payload Integration Plan (PIP). The PIP will identify all STS services required in support of the Space Station operations, including special tests, access requirements, and contingency planning.

Current WP-01 design concepts are highly compatible with standard STS flows, but will acquire late on-pad access for the Logistics Module (specific discussion of the STS Ground Operations Interface is provided in the WP-01 Ground Operations Plan. Early station flights will require close coordination with the STS MCC. This interface will provide backup ground support capability during SSSC checkout and verification.

7.2.2.8 OMV Interface

The SSP becomes a part of the NASA Support System relative to the OMV and

its users. The OMV/User place their requirements on NASA/SS and others as appropriate, like KSC, NSTS, JSC. The existing NASA program management system provides a basic framework for handling program requirements, schedules, management systems.

During Space Station operations the Orbital Maneuvering Vehicle (OMV) strategic planning will be performed in conjunction with the MSFC OMV Control Center. Outside the Space Station CCZ, the ground control has primary tracking and control responsibility. A typical OMV mission conducted from the Space Station entails detailed mission planning on the ground. This is followed by uplink of mission unique instructions to the Space Station. After the OMV is launched and flies beyond the CCZ, the station crew will hand control over to the ground. The ground control then commands the orbit adjust and attitude maneuvers necessary to complete the planned mission. Upon return to the Space Station, the ground hands over control to the station crew for proximity operations. This same scenario applies to an NSTS launched OMV, except the OMV returns to a parking orbit and is retrieved by the NSTS by the orbiter crew.

7.2.2.9 Platform Interface

During normal operation of platforms, the ground has primary control and monitoring. The only time this is not the case is during proximity operations within the Space Station CCZ, or during servicing operations using the OMV. The ground will be responsible for long term and real time mission planning, including orbit maintenance and logistics operations.

Operation of the platforms would be similar to OMV operations except that mission duration is considerably lengthened. Currently, the space based OMV is scheduled

to service the platforms from the Space Station or NSTS remotely or by bringing the platforms to the Space Station and allow easy integration of various POCCs into the Space Station telemetry and command network.

7.2.2.10 Customer Interface

This section describes the customer interfaces for prelaunch payload integration and the operational payload interfaces for command and telemetry support. The purpose of the following approach is to provide a system that is user friendly the the customer.

7.2.2.11 User Philosophy

The mission of the Space Station is to supply the required services to potential customers for the operation of payloads in a stable, controlled environment. With this mission, the payload integration process becomes a task of insuring that physical, command, data, safety, and inter-payload incompatibility issues are resolved. As long as the above issues are resolved, payload reliability, design concepts, and probability of success are the sole responsibility of the user payload organization. Costs associated with providing services to the payloads should be the responsibility of the user payload agency as long as the Space Station provides the agreed upon services.

This approach removes much of the complexity currently experienced in payload integration on the Shuttle by placing the design, test, and verification process within the control and responsibility of the user payload groups. However, the pre-mission verification process inherent in the current Shuttle payload integration process, and the risk reduction built into that process, also becomes the user responsibility.

7.2.2.12 Customer Payload Integration

The Space Station program will identify to prospective payload groups, in the form of an interface document, the physical interface requirements (rack dimensions, standard connections and attach points), safety requirements (acceptable materials, processes, and fire suppression techniques), along with the command and data interface parameters. NASA will also describe the services offered by the Space Station along with the associated cost for each service or combination of services. The payloads can then select the appropriate services for their payload and enter into a written agreement with the Space Station program that specifies the contractual responsibilities for each group.

To facilitate customer communication and payload integration to the Space Station, a single Space Station integration group has been established at Level B. This integration group is responsible for the entire payload integration process from initial customer contact through on-orbit installation. With a single NASA integration organization providing the customer interface, a complex integration process is minimized.

The integration process has the potential for being the greatest source of customer security problems. To limit customer security risks, the exchange of proprietary information between the customer and the NASA Space Station integration group should be limited to areas of safety, test, and physical interface verification. Compatibility issues between payloads and competition for Space Station resources will be resolved by the Space Station Customer Integration Office and the affected payloads representatives. A working group will convene and support each of the Space Station's 90-day missions. If payloads cannot be flown during the same 90-day mission due to incompatibility,

then the payloads will be scheduled for separate flights by the Space Station integration office.

Payloads destined for operation on the Space Station only have to be integrated into one of the logistics system elements rather than on to the Shuttle. This integration scheme allows for a smoother interface between potential customers and the Space Station Customer Integration Office. Integration of the logistics system elements into the Shuttle is a responsibility of the Space Station logistics group.

The integration of customer data/command security procedures and accommodations, other than the physical security provided by the SSSC or other functional geographic centers, will be the responsibility of the payload customer.

7.2.2.13 Customer Telemetry Interface

The telemetry links supplied to the customer at their POCC must be capable of supporting low, medium, and high data volume users; meet NASA communication interfaces, and be expandable for future Space Station program operations. In addition, the communication system should appear to the customer to be separate from other users and appear transparent except for input, output, and planning activities.

The telemetry system that meets these requirements is best accommodated by a distributed network. The distributed network accommodates high, medium, and low data users on the Space Station in a common super-multiplexed data link. The super multiplexed data link is demultiplexed on the ground and the individual user data is then shipped "bent pipe" to the users for processing.

Establishing an operational policy where data is shipped directly to the individual customer POCC and allows the customers

to provide their own data processing capability removes a costly, complex interface resident in past NASA programs. However, processing of user experiment data at NASA ground facilities can be accomplished as an optional service provided to customers. If the customer provides his own processing, the telemetry system becomes "transparent" as far as the Space Station system design is concerned. The concept also limits the complexity of customer integration to the Space Station.

A distributed network allows the system to be adaptable and evolve with the least amount of scarring over the station lifetime. By adding multiplexers for high rate users, submultiplexers for medium rate users, and by adding low rate users to the Space Station management network, the communications subsystem can be expanded to meet all future needs.

7.2.2.14 Customer Command Interface

The command system design and operation for the Space Station should be transparent to the customers and allow the customers to freely interface with their payloads from their POCCs with as little interference from the Space Station program as possible. The following concept supports these requirements.

The concept requires the customers to generate commands at their own POCC facilities and transmit these commands via a "bent pipe" configuration to the Space Station for execution by the payload. For customers who are unable to generate commands at their own facilities, the Space Station Program could provide the command generation and transmission function as an optional service.

The inter-laboratory command coordination and planning function will be the responsibility of a group resident at the SSSC. Inputs concerning services required

by the payloads (power, thermal, crew, etc.) will be by each laboratory support center intra-laboratory group on a monthly, weekly, and daily basis. The payload operation requirements will then be assessed against current Space Station capabilities, operations safety issues, and the requirements of all their payloads for the identification and resolution of conflicts.

Once conflicts are resolved, the individual laboratory support centers will generate, format, and transmit commands from their facilities to the SSSC. The SSSC will combine the various command streams into a common command uplink and transmit the commands to the Space Station.

7.2.2.15 Ground Support Operations Personnel Training

Interactive terminals will provide for ground support operations training system familiarization and practical problem solving exercises. Scripted simulations will employ the use of ground based support equipment, linked via training software and operational communications links, to provide high fidelity exercises. All ground support centers will be involved in console exercises and will experience simulated nominal and contingency operations. Integrated simulations will be minimized. They will be used mainly to check out new interfaces.

Major training facilities will be located at various locations and will contain, where appropriate, interactive simulators and mockups used in the Space Station training program. Space Station modules will be modeled and will contain hardware/software necessary to facilitate the training required. Modules and systems will be capable of data and software links among the station systems and between the station and ground support consoles.

Student terminals used for the self-paced portions of the preflight training program will be capable of high resolution graphics. They will be geographically remote and linked to the main frame.

A training planning and inventory systems should exist to provide the training planners improved efficiency in the training process. It should interact with a mission plans knowledge base and a training knowledge base. Appropriate segments of a training knowledge base will be uplinked for onboard training.

7.2.2.16 Program Phase Deltas

The evolution of ground operation systems is predicated on the development of automation and expert systems. The standard approach for developing these systems is a four step process. The first step in the process is to develop the human operational expertise necessary to perform the function. The man-tended era supplies the medium for establishing the human knowledge base for Space Station operations. Once human "expertise" is developed, the second step can be initiated by converting this knowledge into expert automated systems. As the expert systems are developed, the third step in the process can be performed, i.e., the verification and validation of the expert autonomous system. Verification and validation will be performed by running the expert system in parallel with the existing ground operational system. As confidence in the new expert system is gained and operational problems are overcome, the final step of integrating the new capability into the operating system will be performed. This final step relieves the ground controllers of performing the related systems functions.

During each phase of the Space Station development (man-tended to growth), station functions will be reallocated between

the space and ground segments. The reallocation process will assign a given function to that operational element which provides the most efficient support for that specific development phase. It is expected that single functions will be transferred between the ground and space segments several times during the program lifetime.

The ground operations staffing levels will shift from a ground support intensive effort during the man-tended phase to minimal ground support during the growth phase.

7.2.2.17 Man-tended

During the man-tended phase, the ground support system will be performing all of the station system monitoring functions. The level of ground support personnel performing these functions will be relatively high due to the lack of maturity of expert systems and the nature of the tasks. The ground involvement during this time frame can be characterized as operating in much the same manner as a ground system in support of an unmanned satellite. Ground operations of teleoperated experiment systems are planned.

The operations planning function during the man-tended phase will require all of the IOC planning tasks to be performed on the ground. The planning process will become a two-phase process: one for the unmanned portion of the mission and one for the man-tended timeframe. The unmanned planning periods (monthly, weekly, and daily) will be performed. The man-tended planning cycle will contain long range planning to develop the most efficient payload operations plan for short duration manned visits. A shorter term planning cycle will be used for the routine station maintenance and station repair ac-

tivities that are required since the last manned visit.

Procedures management will be performed in much the same manner for both the man-tended and IOC timeframes. An exception is that two sets of procedures will be required, one for the unmanned operation and a second set for the man-tended operation. These two sets of procedures will have to be validated for overlap to ensure a smooth and safe transition between each operational phase.

The man-tended phase will require a different training philosophy than that employed during the IOC phase. The short duration of the man-tended visits will require the crew to be completely trained prior to the flight. The training techniques and skill levels of the crew will have to closely resemble current NASA shuttle training activities.

7.2.2.18 Growth

The growth version of the Space Station will require minimal real time ground support. During this phase, most system monitoring functions will be automated either on the ground or on the station. The ground support will consist of a small crew providing assistance in contingency situations and performing long range planning and trend analysis on the subsystems and automated software package operation.

Additional mission planning complexity is added to the SSP with the introduction of OTV operations involving rendezvous and docking, refueling, and maintenance with other spacecraft. Additional third party user participation would also be involved in mission planning and design. Rendezvous and orbit translation planning add more complexity and potentially increase resupply requirements for propellants, other consumables, and equipment main-

tenance (at least remove and replace on orbit). Properly established in the beginning of the program, the basic program management functions established for the SSP implementation should suffice for the post-IOC growth period.

7.2.3 On-Orbit Operations

This section provides a description of the operational functions to be performed by the flight crew, hardware and software usage, and the Space Station subsystems operation during the IOC timeframe. Emphasis is placed on the system interfaces and crew activities that take place within the architecture. This concept was developed in conjunction, with Ground Support Operations, to ensure consistent interface definition.

The concept presented includes extensive use of software routines for reducing the crew workload, cross training requirements for all crew members, and the effects that EVA activities have on the availability of crew time.

7.2.3.1 Station Crew

At IOC, the onboard flight crew will contain eight members consisting of one station specialist, two mission specialists, and one payload specialist on each 12 hour shift. Crew members will be NASA personnel due to Space Station administrative and technical requirements. These Space Station requirements include EVA activity (where two crew members are performing an EVA with one crew member monitoring the Space Station subsystems), operation of Space Station subsystems by the mission specialists during the station specialist's day off, simultaneous operation of Space Station equipment, and general safety constraints. The two payload specialists may be USER supplied.

7.2.3.2 Organization

The station crew will be organized with a command structure headed by the director and his deputy. These two individuals will each have the responsibility and authority to make final determination on all matters effecting on-board operations and personnel. They will be assisted with information from the other crew members, ground station support crews, and the station DMS.

The Director will normally be in charge of the primary shift and its crew while the Deputy will have the secondary shift.

In addition to their leadership function, they will be responsible for the IVA operations/monitoring of the modules common subsystems, propulsion system, vehicle accommodations and logistics system. They will have capability to also perform required EVA functions.

The mission specialists and the payload specialists will be responsible for achieving payload mission objectives by onboard operations of assigned payloads and experiments conduction payload and experiment systems monitoring, control and maintenance; to include co-orbiting platform payload maintenance, daily crew activity planning, inventory management and station housekeeping under guidance of the director or deputy director. Mission specialists will be responsible for payload related MSCS, robot, and EVA operations. Each mission specialist will be trained to assist the payload specialists operate specific payloads and experiments. Mission specialists on opposite shifts may be cross-trained to assist on the same payloads and experiments. Skills unique to payload and experiments in the Manufacturing and Technology Lab may be possessed by one mission specialist on each shift while skills unique to the international labs will be possessed by the other

mission specialist will become necessary. For early IOC, onboard NASA mission specialists will be cross trained in Space Station checkout, verification, operations and payload assembly and those tasks involving MSC, robotics, EVA, and arrival and departure support.

Payload specialists will either be NASA or personnel from other organizations, universities, and governments, depending upon payload missions and customers. Payload specialists will be specifically trained for specific payload operations and maintenance. For crews having international makeup, integration of overall payload specialist activities will be the responsibility of a designated NASA international mission specialist.

7.2.3.3. Manning Profile

The manning profile for IOC, i.e., the number and skill levels for the crew and employing agency for the crew and employing agency for the operators of the MTL will be dependent upon the results of functional analysis and the mission profile for any given duty cycle. However, a first estimate of the known functions required to operate and maintain WP-01 systems, indicates that a total of 11,560 hours/year is needed. This is equivalent to a five man crew if one assumes eight productive hours in a twelve hour shift, a six day work week, and a three-day loss every 90 days for crew change-out. For this first estimate, a crew of eight will be necessary to fully operate a four module International Space Station.

7.2.3.4 Operations Planning

The operations planning function includes crew activity planning and flight resource, flight control, maintenance task, and inventory planning. Use will be made of appropriate knowledge bases and interactive

planning systems. Planning for logistics system support, including onboard inventory management, is covered in the Space Station Logistics Resupply Recycle Plan. Crew activity planning for the SSP will consist of two phases of planning in various levels of detail: long-term planning performed by ground teams, and near-term planning performed by the station crew. The hand-over should take the form of a weekly Crew Activity Plan (CAP) developed by the ground planning support function and electronically transmitted to the Space Station. After a review by the station crew of the weekly CAP it will be worked into its daily form by the flight crew.

7.2.3.5 Daily Crew Activity Planning

This near-term CAP is a detailed, task-integrated orbital operations "script" generated and used by the onboard crew as a guide to executing their daily station systems, science, and payload mission activities. Its principal purpose is to facilitate the accomplishment of mission objectives through efficient interleaving of constrained and unconstrained crew tasks and through the economical utilization of expendable station resources such as power, data transmission and storage, and crew time. Near-term planning should require no more than one hour of each crew member's time per day and should largely involve the manipulation of standardized crew activity time/task blocks into a structured array or timeline. It will be the responsibility of the onboard crew to optimize their daily effectiveness while operating in a relatively autonomous environment. Daily CAP activities must be consistent with the ground constraints as well as the current status of the station activities and progress of the experiments and payloads onboard. This planning should not require excessive crew time but will enhance the crew's ability to improve

its own effectiveness. These activities will be performed on an as-available basis by the crew, and belong under the crew's onboard scheduling authority. Accomplishment of these activities will be logged into the software data base by voice or key input, automatic sensing, or automatically recorded unless specified otherwise. Constraints and requirements affecting these or other scheduled crew activities will be maintained in the common flight data base and will be subject to refinement or update by both the ground and onboard crews. There will be some activities which will require detailed checklist type planning.

7.2.3.6 Detailed Event Planning

This category includes activities with flight resource, flight control, and maintenance constraints. Typical activities would be maneuvers for orbit maintenance, systems maintenance which takes systems or equipment offline, earth observations, or operations which require dedicated use of otherwise shared equipment and resources. These activities would be scheduled in as much detail as required in the CAP, making frequent reference to other data base procedures for operations details. The CAP will coordinate all crew activities with onboard or ground resource constraints and trajectory requirements, and provide the onboard framework for daily planning of each individual's schedule. The same scheduling constraints and resources that are available to the ground planners would be provided to the station crew through a common flight data base.

7.2.3.7 Procedures Management

The procedures management function involves review and modification of existing procedures and development of new procedures. Since knowledge for procedures modifications and development is obtained

from experiences in operations, simulations and training, they are best managed through judicious recording of the procedures for recall and use when needed. This is accomplished by use of an operating procedures knowledge base. Such a knowledge base shall contain the Space Station flight data and customer unique flight data file type articles patterned after the NSTS Flight Data File. These shall include station and payload systems operating procedures and checklists, contingency operating procedures, in-flight maintenance and malfunction procedures, flight rules, and medical, and security and safety procedures. The operating procedures knowledge base shall be maintained on the ground and stored onboard for ready crew access. Crew recommended changes and updates to the operating procedures knowledge base shall be transmitted to the SSSC for implementation into the knowledge base.

Space Station Standard Operational Procedures, as developed by ground support personnel, will be system oriented and will contain the following:

- a. References to detailed procedures, drawings, and data stored in the Space Station DMS or transmittable from ground DMS storage.
- b. Description of standards used in the procedure. These will also be available to the DMS display. See Space Station On-Orbit Maintenance Plan for a discussion of these standards.
- c. All caution and warning associated with the procedure. These will be annotated with visual emphasis on the DMS display and an oral tone or verbal note to draw the crew's attention to the possibility of human injury, equipment damage or mission degradation.
- d. Back-out steps in the event that the procedure cannot be safely completed. The back-out steps should leave any critical system operational and noncritical system in a safe condition.
- e. Quality control checks performed on predesignated critical steps. These checks may take one of several forms: certification of accomplishment by another crew member, visual/verbal confirmation by ground support quality personnel, and/or review of the completed procedure via an electronic record of the accomplished procedure by ground support quality. Configuration control will be maintained by the ground using electronic records.
- f. Required interfaces with systems controlled/supported by other flight/ground crews. Communication with those interfaces will be established as a preprocedure event.
- g. Required resource list. Communication resources will have the mode, channel, and call sign specified. Tools and consumables will have their quantity and storage location specified. Electrical power will be specified in terms of watts, frequency, voltage, connection required and available location (outlet). Data support will be specified in terms of rate, storage, software and hardware required.

7.2.3.8 Procedures Implementation

All procedures developed on the ground will be verified on-orbit prior to implementation. On-orbit implementation will be accomplished as scheduled by the daily CAP, and run from the Space Station data management system fixed workstation or portable console. Rehearsal of the procedures may be a part of the on-orbit simulation or run separately prior to the procedure. All tools utilized by the procedure will be confirmed as available and operable prior to commencing the procedure. If a procedure is not successful, the station director may modify the CAP to allow for the formation of a trouble shooting team of flight and ground crew experts for resolution.

7.2.3.9 Procedural Updates/ Modifications

Changes, updates or modifications to procedures will be configuration controlled by an electronic revision system yet to be designed. Block updates will be used unless critical changes are identified for immediate implementation. Any technical change to safety or mission critical procedures will require an on-orbit verification to be run or, at least, the affected section of the procedure to verify the change has not impacted the Space Station in an unforeseen manner.

7.2.3.10 Logistics Module

The logistics system provides Space Station ground-to-orbit logistics, on-orbit supply for extended periods and return-to-ground logistics. Loaded with consumables, hardware, and resupply propellant, the logistics system will be carried into orbit in the STS orbiter cargo bay for changeout at the Space Station. Space Station resupply operations will include exchanging the pressurized logistics ele-

ment, separate pallets and tanksets, and possibly, items carried in the STS Orbiter cabin.

The LM system configuration consists of four major hardware/software elements. These elements are structured to allow clear identification of the areas covered. These areas are primarily bounded by functional assignments and their interfaces. The logistics system will interface with the crew in their performance of the following functions:

- a. Berth pressurized module to a center node interconnect utilizing the MSC. The pressurized module has been designed with two grapple fixtures to allow a hand-off between the RMS and MSC if necessary. However, if such a hand-off is necessary, procedural efficiency would direct the sole use of the MSC. The module has berthing capability designed into one of the nodal interconnect radial ports which also serves as the utility connects for the module to Space Station interfaces. This procedure will be accomplished by and EVA crew operating from the MSC or, as an alternative, IVA from the work station in the Space Station or if the capability is provided, from the NSTS mid-deck if visibility is sufficient from those locations. Three video cameras mounted on Space Station structure will allow monitoring of the berthing. Internal battery power is provided in the pressurized module, and RF communications Space Station monitoring the module

caution and warning system are maintained during the transfer.

- b. Remove supplies as needed from pressurized transporter. The module is pressurized to 101.36 KPd (14.7 psia). Access through the nodal interconnect hatch is gained after a check of the atmospheric condition and after pressure is equalized. The supplies can be removed easily since the storage hardware has been designed with captive attachment hardware which accommodates the manufacture and installation tolerances. Transfer of the storage elements is facilitated by handles installed on each bin or larger assembly.
- c. Exchange experiment racks with interconnects MTL. The racks will be moved IVA by two astronauts. The nodes/interconnects and the hatches have been sized to accommodate a double rack transfer. Utility connections will be through standard interfaces and interface tests will be accomplished by simple BITE go/no-go tests. Returning racks will contain data and non-hazardous products for examination on earth. The fluids carrier will accommodate waste storage including toxic materials.
- d. Transfer and connect fluids carrier to Space Station Structure. This is accomplished IVA by opening automated valves via the station DMS. Fluids are routed through the utility interconnects.
- e. Transfer propellant segment to the Space Station structure. Hookup is via automated connectors or as a backup manual connectors operated by an EVA crew man.
- f. Transfer unpressurized pallets/containers to the Space Station structure. These pallets/containers can be transferred using the MSC, but will have to be unloaded EVA since they contain external payloads and external replacement ORUs.
- g. Transfer return cargo and fuel tank sets from Space Station to orbiter bay. In addition to those discussed in "f" above, returning items from the laboratories include solid and fluid crew wasted not recycled by the ECLSS, ECLSS fluids residuals, propulsion residuals, and ORUs not repairable on the station. Logistic element design for return packaging will facilitate the return of these items. The crew will accomplish these tasks IVA for the pressurized commodities and EVA for the unpressurized. The operations management system will have a Logistics inventory management, subsystem which will keep the status of consumables and cargo by automated input to increment and decrement, calculate cg for the logistics module, and collect operational life data for ORU's. These functions will be automatic, provided the crew makes the necessary data inputs.

7.2.3.11 Vehicle Accommodations

The vehicle accommodations on the Space Station will provide the following services for the OMV and the OTV: 1) deploy-

ment, launch capture and berthing, 2) monitoring while in Space Station control areas, 3) power, thermal, data communications, tracking and lighting, 4) GN2 resupply, and 5) micrometeoroid and space debris protection during storage.

The initial station will utilize a NSTS based OMV that will be used to deploy and retrieve free flying payloads and to perform insitu servicing using an OMV robotic servicer. The station will have accommodations for the OMV such that the OMV can be stored in space between NSTS servicing flights. The accommodations will consist of support structure, automated umbilicals, and an orbital vehicle control console. The accommodations must have the capability to deploy, launch, capture and berth the OMV as well as control it.

The OMV accommodations are planned to be located on the starboard lower keel. The accommodations will include ORUs and special tools for the OMV accommodations elements. An OMV control area will be located in a module pressurized area and will be used to monitor and checkout the OMV and its accommodations and perform telepresence flight control of the OMV.

The accommodations facility will prepare the OMV for a mission and for stowage after the mission has been performed. In addition to controlling the flight of the OMV in the vicinity of the station, the OMV control area will monitor and execute functions in the OMV accommodations.

An OMV Robotic Servicer Kit is a complementary element of the Space Station Vehicle Accommodations System required to enhance the usefulness of the OMV.

The above described vehicle accommodations will interface with the crew in their performance of the following functions:

- a. Grapple OMV, transport and secure to servicing attachments. The MSC will be used to grapple an OMV coasting by on an unpowered approach or one station keeping for pick-up. The crew can be IVA at the control console or EVA at the MSC.
- b. Service the OMV. Although utility connections may be made automatically, they will probably be manually assisted by an EVA crew member. Servicing includes monitor and check out of the OMV systems, GN2 resupply and reconfiguring the OMV with the Robotic Servicer Kit or payloads for deployment.
- c. Deploy the OMV. The MSC will be used to place the OMV into a launch area where the OMV cold gas system can move it to a position where its propulsion system can be fired without contaminating the Space Station.

7.2.3.12 Manipulator and Robot Operations

The Space Station will employ the use of a Mobile Service Center (MSC) and an OMV robotic Servicer Kit. The crew will operate these devices from a workstation. The MSC will be used to manipulate large external structures (i.e., OMV, OTV, Log Modules, ect.), perform inspection and maintenance and act as a platform for EVA activities. Robotic Servicer Kit will be used to partially replace manned EVA

activity required for maintenance and servicing of free flyers.

7.2.3.13 Transfer

Analysis indicates that MSC can be used to transfer the logistics system elements at each resupply. The current concept is made up of a pressurized transportation module for supplies destined for use in the station pressurized volume, an unpressurized transportation module/pallet for supplies that are to be installed on the exterior portion of the station or that can be transported unpressurized and moved into the pressurized volume via the station airlock, a fluids resupply tank set to be attached to the structure and an Propulsion resupply tanker pallet. All of these will have to be transferred from the Orbiter payload bay to their functional positions on the station.

The mechanical connection of these elements may be designed to be automatic, but will require an EVA astronaut to verify proper functioning and alignment. Utility connections may need an EVA astronaut to verify the connection prior to flowing toxic propellants. All other necessary functions will be taken by the MSC being controlled from the module work station or from the mobile platform of the MSC. Estimates to perform the installation/removal of these logistic systems elements indicate that the MSC will be in use for 13.7 hours.

Other WP-01 elements to be transferred are the OMV with or without an attached payload. Simulation efforts to evaluate a candidate operation of an unpowered launch and retrieval relying on the MSC and orbital mechanics indicate this method is achievable.

7.2.3.14 Inspections

The MSC will have high resolution video cameras and lights attached which can be used to inspect WP-01 elements. Routine inspections of the fluid lines for the ECLSS, reboost, and vehicle accommodations can be inspected for visual damage. Detection systems for the fluids in these lines can be added to sniff for leaks. This inspection could be automated and routinely scheduled for low station activity times. The MSC will also act in support of EVA astronaut inspection procedures. Candidates for these inspections are the module thermal radiators, meteorite protection, insulation, external panes of the module windows, OMV and MTL external payloads. Automated photographic documentation of Space Station construction for quality control purposes is also possible.

7.2.3.15 Maintenance

The MSC can be used in the support role as a position aid, tool and ORU transporter and lighting and communication backup to perform maintenance on WP-01 elements.

7.2.3.16 Extravehicular Operations

EVA is manned operations performed outside the pressurized volume of the Space Station. It involves using the airlock.

Airlock: The airlock supports astronauts while they prepare for and conduct extravehicular operations. Activities supported are suit donning and doffing, and airlock pump-down and repressurization, and provision of coolant and atmosphere control to crewmen in the airlock. One airlock is equipped for hyperbaric operations, at

pressures up to 506 kPa (5 atmospheres) above cabin pressure.

EVA is preformed in support of all WP-01 elements. The majority of this support is maintenance Proximity Operations. Proximity operations are the operations conducted exterior, unattached, to the core station out to the limits of operating zone one, a one kilometer (3281 ft) sphere. This includes EVA by the crew when operating untethered and/or with the Manned Maneuvering Unit (MMU), retrieval and launch of OMV with or without payloads, free flying (powered) payloads and/or platforms, and the NSTS orbiter arrival and departure.

Issues involved with WP-01 elements are contamination of module windows, and external MTL experiments; plume impingement on those same systems; collision with all elements; and clearance for earth/space viewing by MTL experiments/payloads.

One approach for retrieval and launch of the OMV and other spacecraft is an unpowered launch and retrieval relying on orbital mechanics and the MSC. In this approach all spacecraft within station control zone are propulsion-safed, i.e., their propulsion and ACS have triple redundant inhibits in place. This unpowered launch and retrieval reduces safety issues and eliminates plume impingement and contamination issues.

7.2.3.17 Payload Operations

Operation of the Manufacturing Technology Laboratory constitutes the major WP-01 interface with payload operations.

The experiments and manufacturing facilities of MTL users are generally under the control of a crewman that manages the operational flow in accordance with

timelined sequence integrated with other crew support as required.

Due to the variety and number of experiments on board the MTL during and mission, customers must write procedures and design experiments so that crew expertise needed for any single experiment is minimized. On-Orbit characterization will be costly in terms of equipment and crew time and involves the risk of error. Where possible, samples shall be returned for characterization. The MTL crew will execute the following tasks on a routine basis.

- a. Obtain equipment from storage and install in racks.
- b. Make all necessary mechanical, electrical, thermal, and data connections and verify preliminary functions.
- c. Load software into computers and initiate check programs.
- d. Remove materials from storage. Prepare samples and insert into test units.
- e. Input processing parameters and initiate experimental procedures.
- f. Perform limited interactive functions preferably initiated by timed sequence or audible alarm.
- g. Operate cameras and recorders.
- h. Shut down experiments and remove samples to prepare for storage, characterization or return.
- i. Perform limited diagnostic and characterization tasks.
- j. Clean up and dispose of wastes.

- k. Remove or exchange equipment from racks and return to storage.
- l. Non-interactive data analysis, reduction and down-linking.
- m. Replenish supplies including gases, cryogenics, liquids, and so forth.
- n. Place or obtain experiments/materials/samples on pallets outside of the MTL environment.
- o. Troubleshoot and repair equipment.

Rapid sample return refers to the means by which samples produced in the MTL can be returned to earth more frequently than the regular 90-day resupply cycle. It may be accomplished by additional shuttle flights or by the adoption of an autonomous, unmanned vehicle which can be deployed for the purpose of returning packages to earth.

Rapid sample return would apply to those samples which would change during on-orbit storage, which require analysis before the process can be repeated or are of such value and sensitivity that they should be returned to earth as soon as possible.

It shall be a design requirement of the MTL that hazardous materials not be admitted to the module environment. All potential hazardous materials, irrespective of the quantities involved, shall be contained so that any predictable sequence of failures will not result in releasing them into the MTL atmosphere or into any other piece of equipment not intended for that purpose. Containment designs shall include active monitoring devices to alter the crew of such failures.

The remaining interface between WP-01 elements and payload operations is the use of the Robotic servicer kit on the OMV.

7.2.3.18 Crew Training Philosophy

Training on the Space Station will use computers, CCTV, video tape/disk and other training media. Standard techniques learned on the ground will be applied to a variety of situations onboard without prior practice. Training on the SS will be a continuation of the training received on the ground. It is not feasible to train crew members to perform all maintenance and repair functions on the Space Station. Training will be provided for basic operational functions and selected emergency functions. On-the-job training must be planned. Appropriate visual aids should be provided to cue troubleshooting and maintenance activities. Training for maintenance or operation of international equipment or payload and training for internationals on the MTL equipment is required.

7.2.3.19 Training Approach

Space Station flight crew training will not be conducted using the traditional classroom/instructor format. Computer technology will be exploited to provide innovative ways to accomplish the required training. Computer-assisted instruction (CAI) and part-task trainers will be incorporated to maximize the training product and student interaction while minimizing regimen normally associated with a formally structured and sequenced curriculum.

Task analysis will be used to identify knowledge levels and performance criteria. All course material will be developed in functionally grouped modules to satisfy training program requirements.

Each module will be stand-alone with no time-table requirement and minimal prerequisites. The complete training program can therefore be tailored to meet the

needs of a variety of agencies, from a refresher course for NASA personnel to the total curriculum required for customers.

These training modules will exist in a training knowledge base maintained on the ground with appropriate information stored onboard when needed for crew access.

Flight crew training will be conducted in two phases. Phase one will be the pre-flight segment emphasizing system familiarization. System knowledge, as identified in the task analysis stage of course development, will be presented in the CAI format and through use of full scale mockups and functional simulators.

Operations planning, procedures management, and system management will require a greater portion of the computer instruction, with problem solving exercises being presented as an integral part of the course exercises.

Mechanical systems requiring method interface will be introduced using CAI, and the greater portion of the material will be presented in the form of scripted simulations and exercises.

MSC, robotic, OMV, and flight control operations will utilize interactive workstations and flight software. The student will be required to perform generic tasks based on anticipated on-orbit operations.

Extravehicular activity (EVA) will be presented using the Manned Maneuvering Unit (MMU) simulator. The student will become familiar with the MMU as a system and will perform tasks normally associated with EVA.

Payload operations training will include only Space Station interfaces. The student will become familiar with station systems required to support payloads (i.e., ther-

mal, power, mechanical, etc.). Payload specific training will be the responsibility of the customer.

Contingency operations training will be included in the appropriate system curriculum. Students will be required to complete problem solving exercises under nominal and anomalous condition. Phase two of the crew training will be conducted on-orbit and will encompass task specific and general refresher training.

Task training will be conducted by non-traditional on-the-job training (OJT) to address each task required to be performed on-orbit including station and experiment tasks identified by the customer. Each specialist will identify the required task and retrieve a "cook-book" checklist (hard copy or video display) from the operations procedures knowledge base which will provide all instructions necessary to complete the task. This method of OJT eliminates duplication of effort and subsequent loss of manhours normally associated with the more traditional demonstration /performance methods.

Refresher training is required to maintain critical skills and practice hand/eye coordination tasks. Because of volume constraints, this training will utilize actual flight hardware and workstations wherever possible. On-orbit tasks will be performed integrating flight stations with the training knowledge base to simulate the operational system. Visual cues will be provided by high resolution video displays to preclude use of external hardware (e.g., MSC, OMV, etc.). Performance will be verified by ground operations via data downlink.

In-flight contingency operations training will be divided into two categories. 1) Training for system malfunctions and anomalies that may impair mission ac-

complishment or station operations with no serious impact on crew safety or subsystem capability. Category one training will be provided via an accessible data base; 2) Training for critical system malfunctions and anomalous events that could adversely impact crew safety or station integrity. Category two will require practice drills such as fire, escape, rescue, etc. Malfunction procedures flow diagrams will be maintained in the operating procedures knowledge base.

Integrated simulations between the Space Station and ground should be used primarily to check out new interfaces.

7.2.3.20 Contingency Operations

The Space Station will be designed to tolerate any single credible failure and continue to function until maintenance can be accomplished during the nominal resupply mission excluding safety critical items. Space Station and payload systems will be designed with sufficient redundancy to provide for mission success and designed for safe degraded operations on non-critical systems. In the event of complete functional loss of a single Space Station module, the station will provide the following capabilities for not less than 28 days to allow a NSTS Orbiter rescue:

- Habitable conditions for the crew
- Access to habitable conditions without EVA
- Orbiter berthing capabilities
- Command and control of the Station by the crew and automatic systems.

Based on these guidelines, contingencies will be responded to by appropriate pre-planned contingency plans maintained in the operating procedures knowledge base. Pre-planned contingency responses will also be developed for contingency situations

where system redundancy capabilities do not exist, i.e., loss of pressure integrity of a module, fire, collision, excessive radiation, and hazardous contamination.

In the event that any one Space Station module becomes uninhabitable for the crew, enough capability will exist in other modules to sustain the crew for not less than 28 days to accomplish rescue or maintenance. If the failed module happens to contain the central systems monitor and control system and the flight control system, at least one other module will also possess the capability of these systems to allow the crew to maintain control of the station.

Space Station pre-planned contingency responses will be developed during the Space Station design and implementation phases and updated throughout the program. Specific mission related contingency responses will be developed during the operations planning process and modified as appropriate for real-time situations. All of the planned contingency responses will be part of the operations procedures knowledge base. The planned contingency response procedures will be verified by simulation prior to approval for use. Operational experience will be used in the modification and development of new responses. If a scheduled resupply mission fails, enough supplies will be onboard to sustain the crew for a nominal recycle of the resupply mission launch.

7.2.3.21 NSTS Interface

After the Space Station has been assembled, the NSTS Orbiter will interface with the Space Station during resupply and possible rescue missions. When the Orbiter approaches the Station and enters the Station command and control zone, the station specialist will monitor the Orbiter approach and docking for safety. During

Orbiter departures, the station specialist will monitor Orbiter undocking and departure until the orbiter is beyond the Space Station safety/control zone.

7.2.3.22 Crew Interface

The NSTS crew cadre is a resource for selection of the Space Station specialists, i.e., the Director and Deputy. On a normal resupply/crew change-out mission the NSTS would transport half the Space Station crew to orbit. Although these missions are baselined at 90-day intervals, mission analyses indicate 45 days to be more likely intervals.

During the rendezvous the NSTS crew has the responsibility for flight management. If the orbiter docks to the Space Station (an event of some concern due to destabilization/contamination) the NSTS crew will retain flight management responsibilities. However, if the MSC were used to grapple an unpowered NSTS approach as described in Proximity Operations, then the point at which orbiter makes the final burn, the SS Director will have flight management control.

After the Orbiter is berthed/docked the SS Director should have administration responsibilities for the total station including the NSTS. However, The NSTS Commander retains the responsibility for the functioning of the orbiter systems. If any logistics elements are handled by the shuttle RMS, then the NSTS Commander has the responsibility for the operation. However, If the logistic elements are grappled (either directly from the cargo bay or in a handover from the orbiter RMS) by the MSC then responsibility reverts to the SS Director at the release of the orbiter attach fittings or RMS. The reverse of these statements is true for return on any logistics elements.

7.2.3.23 Other Interfaces

While docked, the mechanical interface between the orbiter and the Space Station will be the docking module and berthing adaptor. Electrical, communications, and data interfaces are through the docking module. Communication will be hard-line audio and video and data may be copper path or optical fiber. NSTS data and communication to the ground via TDRS may go through the station communication and antenna systems to prevent any NSTS broadcast interference with the station.

There is no planned interface between the NSTS and station ECLSS systems, nor is there any planned interface for the thermal control system. In order to preserve the balance of each system, a connecting module hatch may remain closed.

During the transportation phase, all WP-01 elements will utilize the standards NSTS interfaces in the orbiter payloads bay. These interfaces will be minimized and might only include electrical power for payload support in the logistics module and DMS monitor capabilities of the MTL, vehicle accommodation, propulsion and logistics systems. Thermal control interfaces of these elements with the NSTS is not now planned. Mechanical interfaces will be through standard attach fittings and NSTS FSE, if possible.

7.2.3.24 OMV Operations

Orbital Maneuvering Vehicle (OMV) operations will require significant Space Station support from the crew and OMV Space Station hardware accommodations. The time phasing required to complete an OMV sortie can vary from an hour to several days. This provides a significant variable impacting plans for the required durations of quiescent microgravity condi-

tions for payloads. The crew time required to control the OMV interrupts crew availability for payload operations. The station specialist receives control of the OMV from the OMV ground control, when the OMV reaches the station command and control zone during arrival and relinquishes control to OMV ground control when the OMV exits the zone. Two crew members are required during OMV operations: one to control the OMV, and a second crew member to control the stations systems.

7.2.3.25 OMV Interfaces

An OMV/Space Station Interface Requirements Document will define representative missions such as station fly-around, satellite placement and retrieval, logistics support, and possible station reboost. It will also define operational interfaces in terms of control zones, station controlling functions, and station servicing. The physical interfaces (structural and mechanical, electrical power, communications and data) will be described. Finally, crew systems constraints on the OMV will be defined.

Presently known data about the physical interfaces are described below:

- Structural: Secured at Space Station by OMV trunnion mounts grapple fixture for MSC attachment umbilicals for power and data.
- Power: Low power levels required during monitoring and storage (300W) higher levels required intermittently estimates peak-1200 watts (12-24 hrs preceding flight) battery charging 450W thermal control 350W checkout 400W additional power required internal to Space Station for

control station lighting, refueling provisions (estimated at 500W).

- Communication and Data Management: RF interface to be S-band compatible with OMV/STDN link.

Space Station provides state vector to OMV Space Station Control Center: Initiate pilot control of OMV in vicinity of Space Station monitors OMV checkout and servicing status has ability to: Ascertain OMV position (GPS provided) command maintenance of relative position Initiate approach and departure trajectories Initiate collision avoidance maneuvers.

7.2.3.26 Man-Tended

On-orbit operation of the man-tended station will differ from IOC operations due to differences in crew involved and in the levels of automation employed. With the limited role of humans involved in the on-orbit operations of the man-tended station, the functions of operations planning, procedures and systems management are performed on the ground and will be automated with current generation techniques while more advanced techniques are developed.

Several functions will be performed at the station only during the manned resupply mission. These on-orbit functions include manipulator operations, EVA activities and crew supported payload operations. The level of support that can be provided during a resupply mission is dependent on the length of resupply mission and the crew size. The minimum resupply duration is seven days. Within the projected seven day scenario, only station maintenance and payload changout activities can be accomplished. If the Shuttle on-orbit

time is 14 days, additional payload operations will be performed.

Payload operations will be confined to unmanned operations except for short resupply periods when the NSTS crew will be available for payload support. With this restriction, the payloads will have to be automated, remain dormant between resupply missions, or be capable of reacting to ground control (POCC) commands.

7.2.3.27 Growth

Growth of the Space Station will involve substantial advances in areas of systems management, robotics, automatic rendezvous and docking, and should result in a corresponding increase in the time allocated for crew payload operations.

Crew involvement in the system management functions may be limited to responding to hazardous situations either as a verification of a system's response or as a manual reaction to a malfunction warning. The ground will provide the verification that the autonomous control systems are operating properly.

Anticipated robotics will reduce EVA activity. Advanced robotics systems will be capable of performing maintenance activities without human monitoring once the maintenance task has been identified and programmed. Part of the automation and robotics technology increase will be in the area of rendezvous and docking. With the projected levels of OMV/OTV activities and Shuttle resupply missions for the growth version, automatic rendezvous and docking is necessary to free the crew for other operations.

As the station is automated, the crew productivity will increase in the operation of payloads. Automation will allow a greater payload workload to be accomplished without an increase in crew size. this will

significantly reduce logistics, maintenance, and station procurement costs.

7.3 Logistics and Resupply Approach Planning

The purpose of this section is to provide guidance, identify procedures and resources, and establish policies necessary to develop and implement an integrated logistic support system to support WP-01 project hardware and equipment.

7.3.1 Organizational Relationships and Responsibilities

The SSP Manager is responsible for managing the integration of the SS efforts of the NASA Centers and for managing the integration of customer SS requirements. The logistics integrator is responsible to the SSP manager for performing the integration of SS logistics activities and for incorporation of customer logistics requirements.

The Project Logistics Manager implements the Integrated logistics requirements and those guidelines issued in the future by the SS Logistics Integrator.

The user has the responsibility for defining his logistics requirements. These requirements will be integrated by the SS Logistics Integrator into the SS Logistics System in a manner responsive to the customer.

7.3.2 Logistics Management Information

The Logistics Management Information System (LMIS) will be an automated system that provides management level visibility of logistics activities during the development and operational phases. The system contains master development schedules, logistics element subschedules, data bases responsive to Level B data re-

quirements and project ILS activities, and a performance evaluation mechanism.

7.3.3 Logistics Support Analysis (LSA)

LSA is a set of systematic, comprehensive analyses performed iteratively during conceptual, design, and development phases for the purpose of identifying and optimizing system supportability, and support systems.

The recommended LSA method is MIL-STD-1388-1A tailored to the SS program requirements. This process consists of five basic activities: functional analyses, studies/analyses, design analysis, engineering interfaces, and data verification.

The LSA results will be recorded in the automated LSAR data base. The LSAR data base will be the primary data source for system level requirement summaries.

7.3.4 Logistics Elements

7.3.4.1 Maintenance

Maintenance is a focal point for the majority of the logistics elements. The frequency, type, and level of maintenance directly impacts supply support, OMD, PHS&T, training and personnel, facilities, and support equipment requirements. The most critical step in the identification of maintenance support elements is the formulation of a maintenance concept.

7.3.4.1.1 Maintenance Concept

Maintenance shall be performed at the lowest level of the maintenance structure commensurate with the authorized personnel skills, tools and test equipment, repair parts, and technical documentation. Maintenance shall be accomplished within a three-level maintenance structure (organizational, intermediate, or depot) in which each maintenance action is author-

ized to the level at which it can be effectively achieved.

The concept shall be to remove and replace ORUs at the organizational level. A "REPAIR IN PLACE" determination will be made only when justified by the results of the logistics analysis or on the basis of actual experience, with due consideration to its impact on system operations and turnaround. All levels of maintenance shall be accomplished in a manner that provides support of operational time constraints, prevents deterioration of acceptable operational levels of reliability and safety, ensures timely recycle of failed items to serviceable stocks, and accomplishes this support at minimum practical risk and cost.

7.3.4.2 Reliability Centered Maintenance (RCM)

RCM is a systematic approach for identifying preventive maintenance tasks for an equipment end item and for establishing intervals between maintenance tasks in accordance with a specified set of procedures. RCM analysis consists of analyzing system/equipment reliability and safety data to determine the feasibility and desirability of preventive maintenance tasks, to highlight maintenance problem areas for design review consideration, and to establish the most cost-effective preventive maintenance program for the new system/equipment. RCM logic is applied to the individual failure modes of each reparable item in the system/equipment identified during FMEA, to determine of how impending failures can be detected and corrected in order to preserve the inherent level of reliability and safety in the system/equipment.

7.3.4.3 Technical Documentation

Overall direction and control of technical documentation will reside with the program level technical documentation manager.

7.3.4.3.1 Operations and Maintenance Documentation (OMD)

OMD is the technical documentation used to describe the equipment and provide detailed procedures for organizational, intermediate, and depot level operations and maintenance. This documentation is an integral part of the WP-01 system and the associated support equipment, and is planned, developed, progressively monitored, and updated. Documentation media such as manuals, microfiche, hard disk, and laser disk are analyzed to ascertain the best medium. Supporting analyses, such as LSA, and information such as provisioning technical documentation, are also considered in this process and used to determine the level and scope of SS OMD.

7.3.4.3.2 OMD Validation/Verification (V/V) and Reviews

The review, validation, and verification of technical documentation will be as directed by the procuring activity. In process reviews are conducted for review of technical documentation during the preparation process to provide guidance to the preparing agency as well as to assure that program requirements are being met. Validation is the process whereby the preparing activity tests the technical documentation for accuracy and adequacy. This is accomplished by actual performance of maintenance using the OMD on the system/equipment for which it is written. Verification is the process by which the technical documentation is tested and proved (under procuring activity jurisdic-

tion) to be adequate for operation and maintenance of equipment procured for operational units. A cost effective option is to plan V/V in conjunction with maintainability demonstrations and combine the validation and verification testing as a single test.

7.3.4.3.3 Other OMD

A documentation package shall be prepared for each hardware/software item, facility system, and for selected support equipment. This package shall provide definitive description of facility system/equipment configuration. The following represent typical types of data which are to be included in an OMD package. The exact content will be determined based on complexity of the equipment and users' needs:

SE/Facility System Description and Operation- Contains a concise description of the equipment/facility systems and capabilities and a description of major elements, their functions, and operational criteria. It will contain a block diagram, if required due to complexity, depicting the major elements and an outline of the discrete types of drawings, diagrams, and lists which make up the package.

Mechanical Drawings with Parts Lists - Illustrates the system end-to-end and includes all LRU/ORU components within the system. Drawings may be supplemented by wire run and patch lists. When required, elementary electrical schematics will be provided. These schematics will depict all data of the electrical connection diagram except that wire routings and much of the detailed wire connections to components can be omitted.

Logic Diagrams - Logic diagrams as required to describe the signal flow.

Electromechanical Control Diagrams - These diagrams combine the essential information of elementary electrical schematics and the mechanical schematics and plumbing diagrams.

Documentation List - An indentured list of all pertinent drawings, specifications, and other documentation in the engineering documentation system, required by the operations and maintenance organization to prepare working documents for work reference.

7.3.4.4 Supply Support

The supply support program contains a spares concept, quantification techniques, GFE management procedure, provisioning procedure, inventory control methods, and resupply and return concepts.

7.3.4.4.1 Spares Concept

Existing experience from similar equipment or systems (Skylab, Spacelab, etc.) is utilized in spares selection and quantification. Where experience data does not exist, reliability predictions based on design specifications, statistical analysis, and subsystem criticality are the primary sparing determinants.

Reliability predictions derived from component performance specifications and usage rates derived from mission requirements statements and component density, provide necessary inputs to compute failure rates. These failure rates will be adjusted where MTBF estimates appear unrealistic.

7.3.4.4.2 Quantification

Initial spare/repair parts will be computed using a NASA approved quantification model developed for the STS program. The model algorithm is based on the Pois-

son distribution, a discrete exponential distribution.

7.3.4.4.3 Government Furnished Equipment (GFE)

The prime contractor will be responsible and accountable for all GFE and will maintain and update all equipment documentation supplied with the equipment.

7.3.4.4.4 Spares Provisioning

The initial lay in of spare/repair parts requires a time phased, systematic provisioning program beginning with the identification of long-lead time items no later than critical design review (CDR) and ending with the reprovisioning of spare/repair parts during the operational phase. The provisioning process consists of spares selection, SMR coding, DLSC screening, acquisition, and reprovisioning.

7.3.4.5 Resupply

A primary function of the WP-01 ILS program is to provide cost effective on-orbit resupply of support materiel. Support materiel includes spare/repair parts, support equipment, raw materials, fluids, gases, propellants, and consumables. The primary mode of resupply will be the STS with a scheduled 90-day resupply cycle.

WP-01 logistics is identifying resupply and return requirements as part of the LSA process. The LSAR data base will be continually updated as the system design solidifies and resupply/return quantities become more definable.

7.3.4.6 Facilities

Facilities planning is the process of determining the characteristics and cost of the space and physical facilities which will sat-

isfy the operational and functional requirements of the user. The facilities planning function provides an objective analysis of land usage, site selection, building, structure, and other facilities and equipment requirements to perform specified tasks. It includes the development of preliminary layouts of facilities and equipment and a determination of the engineering and construction feasibility of a project. Facilities requirements established from maintenance flow rates, equipment requirements, and environmental requirements will be identified by the LSA. The decision to build new facilities, or to use existing facilities, considers useability, cost, time, and growth potential. Facilities that will be required include maintenance, training, testing, and payload processing.

7.3.4.7 Packaging, Handling, Storage, and Transportation (PHS&T)

The WP-01 PHS&T program provides analyses, design, and procurement of protective measures for on-orbit hardware and SE throughout the program life cycle.

Transportability requirements and criteria are identified and integrated into the design of flight hardware and SE. This includes ensuring that these requirements/criteria are contractually imposed on contractors/subcontractors. Transportation analyses and cost studies will also consider interface requirements of associated SS projects and of user installations. As program/project changes are made, transportation analyses are updated.

Additionally, the transportation analysis will identify requirements for successful movement of equipment and supplies from suppliers to the user. Analysis will be performed to determine the transportation requirements for operations and support equipment, consumables, and spares.

Methods of environmental protection are evaluated to determine the most effective means of protecting the equipment from damage and reliability degradation resulting from in transit vibration, shock, heat, humidity, contamination, etc.

7.3.4.8 Personnel/Training

A maintenance training program must be developed, implemented, and completed prior to establishing an organic maintenance activity. In addition to the maintenance training program, supplemental training in skilled areas which augment or support the overall maintenance training program must be prepared and presented. The training activity must support the requirements for SS hardware and support equipment organizational, intermediate, and depot maintenance. The training material will be derived from the output of the Training Requirements Analysis (TRA) which, through use of the LSA, will establish the baseline requirements for specific maintenance actions in addition to the skill level and personnel category required to accomplish the task.

7.3.4.9 Support Equipment (SE)

Specific SE will be defined concurrently with the design of the SSPEs. The project shall produce a Support Equipment Plan (SEP). The prime objective of the plan is to identify, define, and schedule all efforts necessary to provide complete and cost-effective support equipment making maximum use of existing hardware/software. A support equipment list shall be developed by the project and provided to users. The list contains the following SE data:

- a. Nomenclature
- b. Part Number

- c. Model Number
- d. Quantity
- e. Location
- f. Serial Number
- g. Item number

7.4 On-Orbit Maintenance Approach Planning

This section provides a description of the approach to WP-01 on-orbit maintenance. It conceptually defines the maintenance concept and support requirements necessary to ensure that the system or equipment attains the specified operational capabilities with minimum life cycle cost. The maintenance concept specifies the who, what, and where aspects of the maintenance requirements. Outputs of the logistics analysis define the support requirements.

7.4.1. Maintenance Types

Maintenance functions are classified into the following major functional types.

7.4.1.1 Preventive (Scheduled)

This classification generally includes tasks such as service/deservice, alignment, component time/cycle replacement, inspection, and other periodic tasks.

7.4.1.2 Reliability Centered Maintenance (RCM)

RCM is a systematic approach for identifying preventive maintenance tasks for an equipment end item and for establishing intervals between maintenance tasks in accordance with a specified set of procedures. RCM analysis consists of analyzing system/equipment reliability and safety data to determine the feasibility and desirability of preventive maintenance tasks, to

highlight maintenance problem areas for design review consideration, and to establish the most cost effective preventive maintenance program for the new system/equipment. RCM logic is applied to the individual failure modes of each repairable item in the system/equipment identified during FMEA, how impending failures can be detected and corrected in order to preserve the inherent level of reliability, and safety in the system/equipment.

7.4.1.3 Corrective (Unscheduled) Maintenance

This classification generally includes such tasks as troubleshooting, fault detection and isolation, diagnostics, disassembly, repair, reassembly, recertification, unscheduled inspection/verification and modification.

A primary systems goal for SS equipment should be "zero maintenance." High reliability and maintainability in equipment design promote this goal.

7.4.1.4 Maintenance Personnel

Trained maintenance personnel will perform maintenance tasks commensurate with their skills and maintenance allocations.

7.4.1.5 Flight Crew

Mission specialists must be trained for general maintenance tasks and will primarily perform PM, before-operations, during-operations, and after-operations maintenance tasks.

Station specialists must be formally trained in general and speciality maintenance skills, e.g.: Soldering, troubleshooting, calibration, system analysis and fault detection, spot welding, etc. Station specialists will backup mission specialist maintenance activities and will be the fo-

cal point for all flight maintenance requirements to include prime interface with ground support.

7.4.1.6 Ground Crew

Ground maintenance activities will include a team of maintenance experts trained and experienced in various maintenance disciplines with a prime role of providing maintenance information and assistance to the on-orbit station specialist. Contingencies may require quick-reaction response from this ground support team to provide immediate "fix" instructions.

7.4.1.7 Contact Teams

Contact team support is that maintenance provided by intermediate/depot (including contractors) to a lower level maintenance activity. This support will primarily involve repair operations; however, they may also be utilized for technical assistance/liaison.

Fly-in contact teams will be comprised of depot level maintenance personnel to provide backup for station maintenance personnel (station specialists) on an as needed basis. Scheduled fly-in teams will provide refurbishment, overhaul and modifications.

Ground contact teams will be composed of separate intermediate and depot contact teams to provide backup and corrective maintenance support at the organization/user location.

7.4.2 Procedures and Data Development

On-orbit maintenance procedures for each ORU will be developed by the contractor with evaluations by on-orbit crew personnel. Procedure development will commence with task analysis during the design and will include recommended tools and specialty training requirements.

All task procedures and data will be determined as part of the LSA process, developed, and stored in an electronic data format that can be easily transferred between system hardware suppliers, users, NASA centers, and between the on-orbit and the ground Space Station activities.

Procedures for ORU maintenance and repair will be demonstrated using protoflight subsystems and progressing from ground facilities to zero-gravity environments, where practical.

Known and projected maintenance requirements for each period between resupply missions shall be developed and submitted to the WP-01 project for incorporation into the overall mission operations requirements document for the specified time period.

7.4.3 Mission Set Maintenance Procedures

The maintenance plan will identify all maintenance actions and the associated procedures. The plan and the maintenance procedures, will be uplinked to the Space Station SS or provided in replacement video disk format, as appropriate during resupply. The same information will drive the ground logistics system for spares provisioning and positioning to support the on-orbit maintenance plan. A preventive maintenance schedule and forecast of failure schedule will be developed using life cycle data of the MMDS and will be part of the mission cycle maintenance plan. Data will be dynamic, updated by and responsive to the failure experience of the maturing Space Station program.

8.0 ADVANCED DEVELOPMENT

Design and develop of experimental hardware which lays the framework for the advanced development process has played a major role in the study effort.

8.1 Advanced Development Activities

A summary of the Advanced Development Activities is summarized by the following items:

- AR-1 Automation and Robotics
EC-1 ECLSS Water Management
- EC-2 ECLSS Air Management
- EC-3 Air and Water Monitors
- EC-4 Component/Subsystem Test and Evaluation
- PO-1&2 Electric Power Distribution Network and Control Architecture
- TH-1 Thermal Interface Development
- MS-1 MPAC Element Demonstrator
- AP-1 Propulsion and Fluid Systems
- SM-1 Meteoroid/Debris Impact Shield Testing
- DM-1 System Controller Development for Data Management Systems
- DM-2 Hierarchical Controller Development

8.1.1 AR-1 Automation and Robotics

8.1.1.1 Description

Automation and Robotics is a multi-tasked program with the primary aim to reduce crew time for Operation and Main-

tenance tasks on the Space Station. This section is broken down into the following tasks:

a. Robotics Advisory Board

Assemble recognized experts in A&R community to review present space related A&R activities and develop the direction of future A&R work.

b. Robotics Logistics System

Fabricate Hardware and develop Software to demonstrate the concept of a two armed manipulator for managing logistic elements within the Space Station logistic module.

c. On-board Crew Scheduler

Demonstrate a prototype on-board scheduler with rudimentary algorithms for more realistic utilities resource and crew task scheduling.

d. Remote Space System Servicing Development

Explore and evaluate the effects of teleoperation with and without time delay. Obtain learning curves of different subjects performing ORU changeouts. The data obtained will be used as design requirements for future remote space servicing systems.

e. FMEA Assistant

Implement a knowledge based system that will serve as an engineering aid in performing FMEA. The system uses an object-based message passing representation to capture component failure information and system relationships among components.

8.1.1.2 PRODUCTS

The products that will result from this multi-tasked effort are:

a. Robotics Advisory Board

Transfer of A&R knowledge to design efforts, and identification of future A&R activities.

b. Robotics Logistics System

Definition of IVA robotics requirements for Inventory Manipulation on Space Station.

c. On Board Crew Scheduler

Definition of an on-board crew scheduler.

d. Remote Space System Servicing Development

Design requirements for servicer, workstations, and ORUs.

e. FMEA Assistant

Tool for FMEA and single and multiple failure point predictions.

8.1.1.3 Test Results Summary

Test results are expected to show the capability and feasibility of concepts systems such as the Robotics Logistics System, the On-board Crew Scheduler, and the FMEA assistant on Space Station. Additionally, the learning curve and design requirement information obtained from the Remote Space System Servicing and Robotics Advisory Board tasks will drive station operation requirements and subsystem design/scarring for implementation of IOC and growth automation. Space Station utility and productivity is dependent upon incorporation of flexible automated systems to relieve the crew from dangerous, bor-

ing, repetitive, and computationally intensive tasks.

8.1.2 EC-1 ECLSS Water Management

8.1.2.1 Description

Develop a technique for microorganism growth prevention in ECLSS condensing heat exchangers. Providing a heat exchanger design compatible with the growth prevention method is a parallel effort. The test procedures developed will be conducted over a four month period on several conceptual configurations.

Coordinate with Umpqua Research Company in evaluation of a multifiltration unit for reclamation of wash water. Unit will be designed and built by Umpqua and tested in the Boeing ECLSS Laboratory by processing typical hygiene water. Long term parametric data will be obtained relative to water purity (e.g. expendables, energy costs, recovery efficiency, weight and volume penalties).

Boeing will also evaluate hollow fiber membrane reverse osmosis unit in processing hygiene water. Data comparable with the Umpqua system will be obtained and reported. Testing will be accomplished by Boeing.

A bench test unit for mixing pretreatment material with urine will be designed and built per Boeing/NASA requirements. The unit will be tested in the Boeing ECLSS Laboratory. A vapor compression distillation for water recovery from pretreated urine will be fabricated for utilization in MSFC ECLSS testbed.

8.1.2.2 Test Results Summary

Testing to evaluate the most effective technique for control of microbic growth in the

Space Station humidity control heat exchanger is in progress. The methods; high temperature (250°F), biocide addition (iodine) and ultraviolet light are being evaluated. To date, the high temperature technique has been implemented and indicates a high kill effectiveness.

8.1.2.1.1 Urine Pretreat Mixture (UPM)

The urine pretreatment mixer which has the capability to add both liquid and solid pretreatment formulations was evaluated. Functional testing verified the capability of the hardware to add specific amounts of both liquid and solid components to meet a wide range of formulation specifications.

During the test program, the four formulations evaluated were: 1) sulfuric acid with 10gr/liter of urine oxione; 2) sulfuric acid with 5 gr/liter of urine oxione; 3) sulfuric acid and hexadecyl trimethyl ammonium bromide with 0.04 gr/liter urine; and 4) sulfuric acid with 0.18 gr/liter chromic acid. Results indicate that all formulations accomplish stabilization of free ammonia and microbial growth equally well. For Space Station application, the liquid treatment formulations appear to show lower expendable requirements and ease of operation when handling of solids is considered. The UPM has been delivered to MSFC for utilization in integrated ECLSS testing.

Hollow Fiber Reverse Osmosis (HFRO) and Multifiltration Water Recovery Units (M/F) functional tests have been completed.

8.1.2.1.2 Vapor Compression Distillation (VCD)

A three man capacity evaporative urine recovery has been fabricated and acceptance tested. Utilizing distilled water, the acceptance tests have reverified that the three

man design recovery capacity has been exceeded. The unit has been delivered to MSFC for utilization in integrated testing.

8.1.3 EC-2 ECLSS Air Management

8.1.3.1 Description

Boeing, with the AiResearch Mfg. Co., will develop an upgraded Skylab type of molecular sieve unit for CO₂ removal. Based on NASA requirements, AiResearch will design a four-bed, water-save, CO₂-save molecular sieve for evaluation by the Boeing ECLSS Laboratory. An alternate system using a recently developed hydrophobic carbon-based material will also be evaluated relative to the first system. Results will provide the information required for trade studies relative to competing CO₂ removal such as solid amine and electrodepolarization.

The AiResearch Mfg. Co. will design and build a conceptual bench-test unit capable of liquifying and storing carbon dioxide as provided by the mole sieve collection system. This unit will be available for utilization in MSFC testbed.

Life Systems, Inc. will design, fabricate and test a static feed electrolysis system and Bosch CO₂ reduction system for utilization in MSFC ECLSS simulator.

8.1.3.2 Test Results Summary

8.1.3.2.1 Molecular Sieve and Liquefaction System

The four bed molecular sieve was designed and fabricated utilizing the major components from two Skylab 2 bed systems (sorbent/desiccate canisters and process air valving). The liquefaction system was fabricated utilizing a high pressure oxygen compress from an Air Force program. Acceptance testing of both units have verified that desired functions of car-

bon dioxide removal and liquefaction are accomplished. The predicted carbon dioxide removal performance utilizing the capacity for desiccant and absorbent available in the Skylab canisters was a three man capacity (0.275 LBSCO₂/HR) with a carbon dioxide inlet partial pressure of 3.0 mmHg. Test data show that a three man capacity is achieved with a 3.5 mmHg carbon dioxide partial pressure which is adequate performance to satisfy integrated ECLSS system testing objectives. The carbon dioxide removal and liquefaction system has been delivered to MSFC for integrated ECLSS testing.

8.1.3.2.2 Static Feed Water Electrolysis System (SFWES)

The SFWES has been fabricated and acceptance tested. Test data has reverified that the design capacity has been met. The SFWES has been delivered to MSFC for integrated testing.

8.1.3.2.3 Bosch Carbon Dioxide Reduction

The fabrication of the Bosch system is complete and the unit is in acceptance test at life systems prior to delivery to MSFC for integrated testing.

8.1.4 EC-3 Air and Water Monitors

8.1.4.1 Description

Boeing, with Perkin-Elmer, will develop a test unit for monitoring major constituents and trace contaminants in the atmosphere. Monitoring requirements will be defined and prior gas chromatograph-mass spectrometer systems reviewed for applicability to Space Station. An IOC design will be fabricated for test evaluation. Techniques for analyzing carbon monoxide (CO not amendable to mass spec analysis) will be investigated and IOC analyzers evaluated.

Boeing will assist NASA in obtaining the best available information on instruments for water quality monitoring (pH, conductivity and total organic carbon). Based on the results of industry response, an improved breadboard water quality monitor will be designed and fabricated for bench testing at the Boeing ECLSS Laboratory.

8.1.4.2 Test Results Summary

8.1.4.2.1 Air Monitor

The Spacelab Trace Gas Analyzer (TGA) has been made operational and performance of known gases selected from the original design criteria have been verified. A training course has been conducted at Perkin-Elmer for members of NASA (KSC and MSFC) and Boeing engineering. The training course was provided to train the individuals who will utilize the TGA during integrated ECLSS testing.

8.1.4.2.2 Water Quality Monitor

The water quality monitor which monitors pH, conductivity and total organics for both potable and hygiene was evaluated and performance characterized. The monitor has been delivered to MSFC for integrated testing.

8.1.5 EC-4 Component/Subsystem Test and Evaluation

8.1.5.1 Description

Boeing will work with its subcontractor team and NASA to provide the systems for an integrated ECLSS test capability. Selected breadboard and bench test units, developed by Boeing and subcontractors will be tested in the Boeing ECLSS Laboratory then provided to MSFC for use in the ECLSS test bed. Subsystems supplied by other vendors will also be tested, as they become available.

by other vendors will also be tested, as they become available.

The following subsystems have been acceptance tested at suppliers and delivered to NASA for integrated ECLSS testing:

- a. Vapor Compression Distillation Subsystem
- b. Carbon Dioxide Removal and Liquefaction Subsystem
- c. Static Feed Water Electrolysis Subsystem

Bosch Carbon Dioxide Reduction Subsystem will be assembled. Trace Gas Analyzer, performance evaluation complete. Water Quality Monitor Performance testing accomplished.

Note: This is a MSFC conducted test.

8.1.6 PO1/2 Electric Power Distribution Network and Control Architecture

8.1.6.1 Description

PO-1 determines the feasibility of using high voltage (vs 28VDC) at 20 kHz electrical power distribution within the common module.

PO-2 determines degree of control and automation required for common module electric power distribution system.

The original intent of this task was to determine the feasibility of using 200V for power distribution within the module and to evaluate the degree of control and automation required for module power distribution.

Because of the NASA decision to baseline 400 Hz in December 1985, the plans were revised to evaluate the performance of SOLID STATE remote control switches

for control and monitor of electrical power within the module.

8.1.6.2 Task Products

PO-1 - Two contracts were let, to Sunstrand and Westinghouse to study and analyze requirements, conduct trade studies and provide recommendations for two types of solid-state power switches for possible use in the Space Station electrical power distribution systems. During progress reviews various changes in the scope of work took place. The most critical change was from 20 KHz to 400 Hz. The Sunstrand contract was terminated with a final report, dated July 6, 1986. The Westinghouse contract was continued with the additional requirement of delivery of remote-control solid-state switches. One 20 Ampere and three 50 Ampere 400 Hz remote-control solid-state switches were delivered on March 25, 1986.

PO-2 - A test facility for evaluation of the remote-control solid-state switches with full power water cooled loads was designed and fabricated. The facility was completed and the switches installed by July 15, 1986. The switches had to be returned to Westinghouse for modification from 200V to 115V. Functional testing of the switches was complete by August 1, 1986.

8.1.6.3 Test Results

The remote-control solid-state switches include the following features:

- All solid state switching elements parallel inverse SCRs
- Over current trip
- Under voltage drop-out
- Over temperature trip

- Data bus compatible

- a. On/Off
- b. Reset
- c. BIT
- d. Measure current flow
- e. Measure load voltage
- f. Report StatusReady

ON Tripped BIT operation

All these functions were verified as operational.

8.1.6.4 Findings and Recommendations

- Determine accuracy of voltage and current sensors over time and temperature.
- Verify SCR temperature and cooling requirements.
- Time response of each function should be investigated.
- Current packaging is operational "Brass" board. Repackaging for minimum size and weight should be investigated.
- SCR selection for 20 kHz should be investigated.

8.1.7 TH-1 Thermal Interface Development

8.1.7.1 Description

Design, fabricate and test an interface heat exchanger between the internal loop and the central radiator system, and between the internal loop and the Body Mounted Radiator (BMR).

8.1.7.2 Task Products

Develop and fabricate interface heat exchanger and heat pipe radiator and the accessory hardware components necessary for successful test of the system in thermal vacuum chamber.

Develop and fabricate a 2-phase compact heat exchanger and an ammonia test facility for successful testing of 2-phase heat exchanger performance.

8.1.7.3 Test Result Summary

Analysis and test has shown that the liquid sleeve heat exchanger that is developed under this task is thermally efficient and mechanically sound in simulated operating environment.

A compact 2-phase heat exchanger was designed that has shown (by analyses) that it can transfer 20 kW of energy at the prescribed operating temperature range of the Space Station central thermal bus. This heat exchanger measures 4" x 12" x 3.5" and weighs less than 10 lbs. Tests to demonstrate the predicted performance will be accomplished.

8.1.7.4 Findings

The thermal vacuum chamber test for the radiator heat exchanger has been completed. Preliminary data has shown that this heat exchanger operates well in vacuum condition and that it is thermally efficient. It is therefore recommended that this concept be kept as a possible interface for the heat pipe radiator.

If predicted performance is verified by test, a light weight alternative to the contact heat exchanger could be established.

Figure 8.1.7.4-1 shows the schematic of 2-phase heat exchanger test facility.

8.1.8 MS-1 MPAC Element Demonstrator

8.1.8.1 Description

This task was originally formulated as the construction and empirical study of the optimum configuration of an OMV Control Station. Subsequently, the description of work has been changed to reflect more nearly the actual resources available to be allocated to it. The title of the task has been changed from "OMV Control Station Development" to "MPAC Element Demonstrator," and the task elements to be accomplished have also been revised to reflect the capabilities inherent in the less expensive and less sophisticated console built under this umbrella.

The specified hardware includes programmable switches, CRTs, disk storage, and hand controllers. These devices might be considered as elements of the MPAC, as the term is generally understood, but not as the MPAC itself. The services performed include display control options for OMV simulation, storage of simulation data and simulation input devices. Obviously, this device will not be a replica of the physical device that would be installed on the SS, but rather a functional representation of the controls, displays, and some of the capabilities of the workstation electronics core. This is an engineering device, useful for gathering data for design decisions, and thus aiding the design of the workstations to be installed in Space Station.

The console or element demonstrator, which is being built under the auspices of MS-1, is used as a research tool to collect some comparative data on controls and displays. There is no intent to actually de-

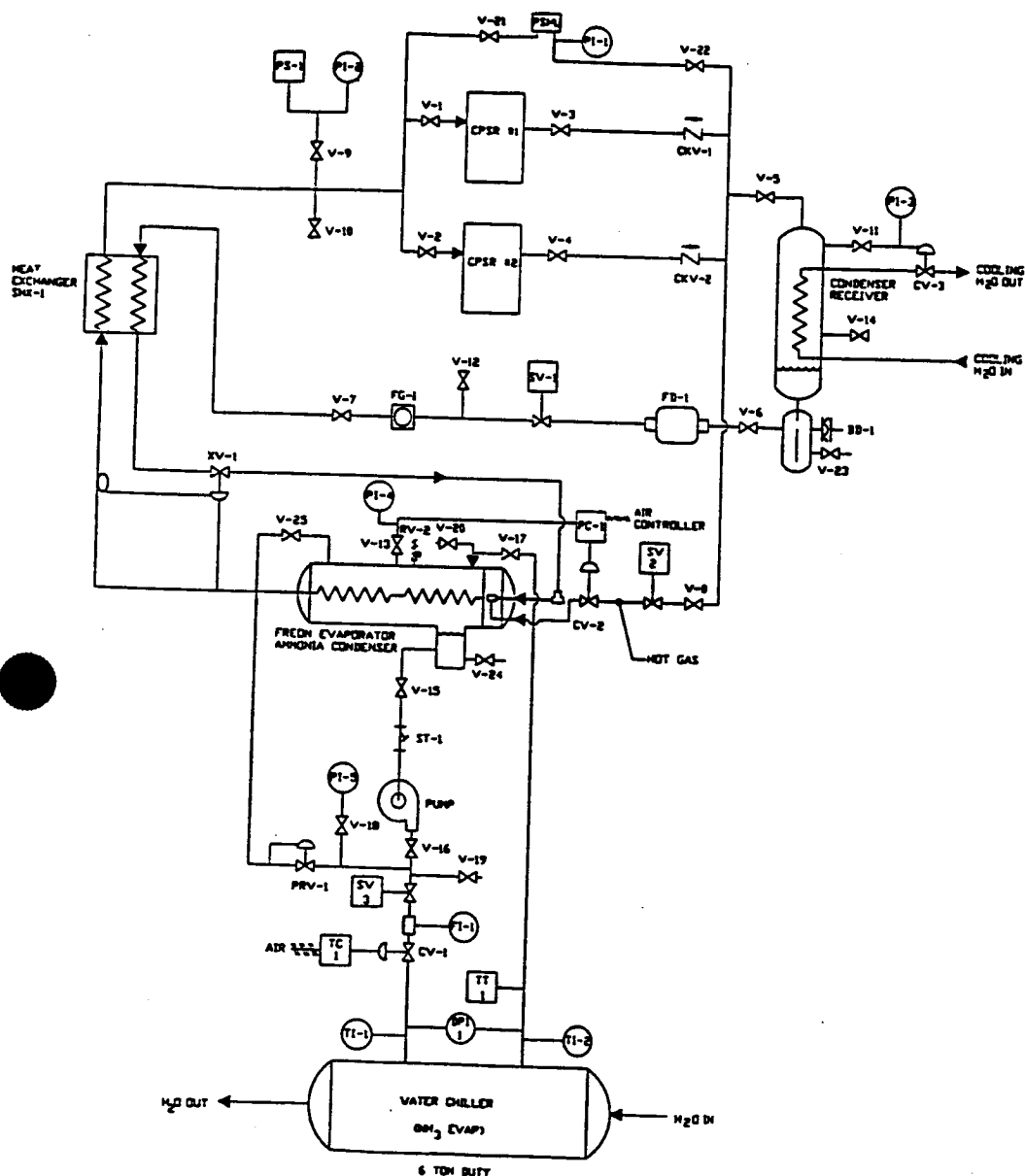
sign an MPAC or the MPAC or a representation of any actual piece of hardware.

To be consistent with the following definitions from the PDRD, paragraph 2.2.10 of JSC 30000, nomenclature will need to be carefully defined. The term "multipurpose applications console" has been used by some to mean nearly the same thing that the PDRD uses the term "workstation" to mean. The PDRD would probably use the label of OMV workstation for the relatively narrow mission of controlling the OMV. It would further designate it the primary OMV workstation.

"Crewstation--any location in the space station where a task or activity is performed. Each crew station shall have a consistent local vertical. For displays and controls utilizing the overhead, the local up is consistent with rotation of the head back in order to look up. For function allocation, the primary viewing and access areas are defined as those areas within which are located the most highly utilized equipment. That equipment which is less frequently utilized and less critical is located in progressively less viewable and accessible areas of the crew station. Some crew station are workstations."

"Workstation--some crew stations are workstations. A workstation is a dedicated structure at which SS tasks, such as laboratory work, subsystems monitoring, inventory management, and crew support tasks (e.g., health maintenance monitoring) are performed. A workstation may contain an electronics core (e.g., a multipurpose applications console, comprised of displays, controls, SSIS and video interfaces, and resident firmware), crew support equipment (e.g., cameras, restraints, etc.), crew job aids, lighting and controls, and stowage, integrated into a physical support structure. Workstations may be fixed or portable. For some tasks one

ORIGINAL PAGE IS
OF POOR QUALITY



- BB-1 BURST DISC
- CKV-1 CHECK VALVE R-12 COMPRESSOR DISCHARGE
- CKV-2 CHECK VALVE R-12 COMPRESSOR DISCHARGE
- CV-1 CONTROL VALVE NH₃ FLOW CONTROL
- CV-2 CONTROL VALVE R-12 HOT GAS CONTROL
- CV-3 CONTROL VALVE WATER FREON PRESSURE
- DP-1 DIFFERENTIAL PRESSURE REGULATOR
- FG-1 FLOW INDICATOR R-12
- FG-2 FLOW INDICATOR NH₃
- PC-1 PRESSURE CONTROLLER
- PI-1 PRESSURE GAUGE R-12 COMPRESSOR DISCHARGE
- PI-2 PRESSURE GAUGE R-12 COMPRESSOR SUCTION
- PI-3 PRESSURE GAUGE R-12 CONDENSER
- PI-4 PRESSURE GAUGE NH₃ CONDENSER
- PI-5 PRESSURE GAUGE NH₃ PUMP DISCHARGE
- PP-1 A P PRESSURE GAUGE NH₃ EVAPORATOR
- PRV-1 PRESSURE RELIEF VALVE SET AT 15 PSIG
- PS-1 PRESSURE SWITCH R-12 CAPACITY CONTROL
- PS-2 PRESSURE SWITCH R-12 HIGH/LOW
- RV-1 RELIEF VALVE NH₃ CONDENSER
- SHE-1 HEAT EXCHANGER R-12 GAS TO LIQUID
- ST-1 STRAINER NH₃ LIQUID
- SV-1 SOLENOID VALVE R-12 LIQUID
- SV-2 SOLENOID VALVE R-12 HOT GAS
- SV-3 SOLENOID VALVE NH₃ LIQUID
- TC-1 TEMPERATURE CONTROLLER H₂O OUT
- TI-1 TEMPERATURE INDICATOR NH₃ LIQUID IN
- TI-2 TEMPERATURE INDICATOR NH₃ LIQUID OUT
- TI-3 TEMPERATURE PROBE H₂O OUT
- V-1 VALVE COMPRESSOR #1 INLET
- V-2 VALVE COMPRESSOR #2 INLET
- V-3 VALVE COMPRESSOR #1 DISCHARGE
- V-4 VALVE COMPRESSOR #2 DISCHARGE
- V-5 VALVE COND/RECEIVER INLET
- V-6 VALVE ISOLATION
- V-7 VALVE ISOLATION
- V-8 VALVE H₂O BY PASS
- V-9 VALVE ISOLATION
- V-10 VALVE SERVICE GAS
- V-11 VALVE COND/RECEIVER PRESSURE CONTROL
- V-12 VALVE SERVICE LIQUID
- V-13 VALVE ISOLATION
- V-14 VALVE COND/RECEIVER DRAIN
- V-15 VALVE NH₃ PUMP INLET BLOCK
- V-16 VALVE NH₃ PUMP DISCHARGE BLOCK
- V-17 VALVE NH₃ CONDENSER INLET BLOCK
- V-18 VALVE NH₃ ISOLATION
- V-19 VALVE NH₃ SERVICE
- V-20 VALVE NH₃ SERVICE
- V-21 VALVE NH₃ ISOLATION
- V-22 VALVE ISOLATION
- V-23 VALVE SERVICE
- V-24 VALVE DRAIN
- V-25 VALVE ISOLATION
- XV-1 EXPANSION VALVE R-12

FIGURE 8.1.7.4-1 INTERFACE HEAT EXCHANGER TEST FACILITY SCHEMATIC

workstation may be designated as a primary workstation, where that activity is usually performed. Other workstations, capable of supporting that activity, are defined as alternate workstations."

The objective of MS-1 is to build and deliver a console which can be used to demonstrate elements of input and output: components of the man-machine interface (or MMI).

8.1.8.2 Products

The elements that are to be included in this device are not intended to be exact duplicates of the hardware that might actually fly in the SS, but rather to functionally represent that hardware so that some early useful work can be accomplished. Accordingly, the degree of fidelity is not what is usually considered to be simulation quality. One of the more difficult decisions is to determine the number and type of hand controllers to be installed to operate the MRMS and the OMV. There is some background available for the configuration employing two controllers, each with three degrees of freedom (dof), but no published data that has been identified that addresses the configuration employing a single controller with six dof.

Control of the Canadian-built manipulator arm on the shuttle orbiter is done using two hand controllers, each with control of three degrees of freedom. The position normally assumed by the astronaut to perform this control function is somewhat awkward, requiring the operator to push his/her face forwards to get the best possible outside view out of the small window provided, and making the position of the right hand actually behind the body while control movements are being made. The fact that the astronauts have been able to accomplish useful work with this configuration seems attributable to human flexibility and ability to learn very unnatural

tasks when highly motivated, rather than to the "goodness" of the design.

An engineering prototype of a single controller, capable of controlling six degrees of freedom, has been on loan to MSFC for the last two or three years from CAE of Canada, and has been used to control a robotic arm in some experimental settings. Information gathered from NASA indicate that the six dof controller is vastly superior to a pair of three dof controllers for this kind of task. A small drift developed in their arm, which needed to be compensated for by the experimental operators if they were to complete their tasks. Operators using a pair of three dof controllers were unable to effectively overcome the drift, while operators using a single six dof controller were able to compensate for the drift almost instinctively, and learned to overcome it in a matter of seconds. This seems to strongly support the preferability of a six dof controller, vis-a-vis a pair of three dof controllers, for control of the MRMS.

Originally, it was thought that two, three dof controllers would be advantageous for OMV operations because they would insure against control inputs being confounded between translations and rotations at some critical mission juncture; say, during the actual final stages of docking engagement following rendezvous. The consequences of translating a few feet when you really wanted to roll a few degrees could be very expensive, and perhaps even disastrous! However, that problem could be resolved with some simple device such as a button or voice command to lockout unwanted control channel inputs. Therefore, separate controls for translation and rotation may not necessarily be required to support OMV operations.

A pair of three dof hand controllers and a single six dof controller are required. They

need to put out an analog signal than can be input to an IBM PC/AT in which the control station operating software will reside. The preliminary nature of this effort and the recognition that any substantive conclusions are likely to be replicated means that useful work can be accomplished with what could be called "arcade quality" devices.

Controls include multifunction, programmable switches and means that the legends to be displayed thereon for selected mission phase tasks needs to be developed and evaluated. The flexibility afforded for designers of man-machine interfaces by the advent of programmable switches is not yet well understood. Research to date has not found any significant performance advantage for either text or icons as representations for higher level commands.

To fulfill the requirements for the programmable switches in this endeavor, a panel of some 20 switches which can be controlled by software to display and control different legends dependent upon the legend displayed, is included.

The three dof and six dof controllers will make inputs to control station software residing in a PC/AT through an interface box developed in conjunction with UAH. The outputs from the hand controllers go into a TECMAR Labtender board in the AT. This board can accommodate up to 16 single ended ADC channels, 8 DAC channels and 24 bit digital IO channels. All ADC and DAC channels have eight bit resolution, adequate for this application.

Output from the control station computer goes into the simulation host computer (a microVax II) where the OMV dynamic math model resides.

Output from the simulation host computer will go into the Alcyon front end of the GTI Poly 2000, which will serve as a

throughput device to communicate to the Poly 2000 System Control Module for generation of graphics images. The output from the Alcyon to the Poly will be the 12 data points that make up the state vector of the OMV and a control word. The 12 values are the X, Y, and Z coordinates and roll, pitch and yaw and the rates of change of each.

The output of the Poly 2000 is a picture of the Space Station, as seen from the OMV camera. This visual display is intended as a visual supplement to the digital state vector information that will be available on the local display from the control station AT.

The programmable touch panel (PTP) will be interfaced to the AT using a dual RS-422 interface. The PTP contains 20 programmable display modules with the associated electronics built into the panel, and a separate box for the power supply.

8.1.8.3 Test Results Summary

The selected hardware components have all been received and built into a single integrated console rack assembled from commercially available sources. Correct operation of the controllers and their compatibility with the visual displays generated by the Poly 2000 have been verified with preliminary subjects, and the final "fine-tuning" of the control operations are completed. The collection of the empirical comparative data will be completed.

8.1.9 AP-1 Propulsion and Fluids Systems

The propulsion and fluids systems advanced development program (AP-1) consists of four tasks, long-life thrusters, augmented N₂H₄ thruster, minimum spill connector and O₂/H₂ test.

8.1.9.1 Long Life Thruster

8.1.9.1.1 Description

The program objective was: show feasibility of a hydrazine thruster capable of providing greater than 750,000 lb-sec total impulse. The test 25-lb. rocket was an extended life version of flight and production proven inertial upper stage (IUS) rocket engine assembly.

The extended life rocket is identical to the IUS engine except that Haynes 25 catalyst retention screens were replaced with platinum-iridium alloy. Life testing consisted of a complex array of numerous short duration pulses followed by a long steady-state pulses followed by both short and long cool downs. The tested pattern simulated both reboost and ACS requirements. A typical pattern is shown in Figure 8.1.9.1.1-1. In addition, to satisfy possible throttling requirements, tests were conducted with thrust levels set at 25 lbs. 18 lbs., and 10 lbs. Durations at each level were approximately equal.

8.1.9.1.2 Test Result Summary

The purpose of the test was to fire at least 750,000 lb-sec of impulse through the thruster. The test program accumulated 11,980 valve cycles and 786,100 lbf-sec total impulse. The test was terminated because of depletion of the available monopropellant hydrazine allocated for this program. All firings used monopropellant grade hydrazine containing 0.45% maximum aniline.

For steady-state baseline performance (100 seconds pulse or greater), the nominal thrusts were 25.4/18.2/10.1 lbf with Isp respectively 231.8/229.0/222.7 at 330/220/110 psia inlet pressures. Exhaust gas samples were taken during steady-state operation. The percent ammonia dissociation ranged from 48.8% to 61% and

generally increased with decreasing inlet pressure and aniline content.

For pulsing baseline, minimum impulse bits of 1.267/0.948/0.593 lbf-sec were recorded at 330/220/110 psia inlet pressures, respectively.

Beginning of life oscillatory roughness was + 3.0/4.6/4.5% and end of life roughness was + 14.3/8.8/3.7% at 330/220/110 psia inlet pressures, respectively. Based on an extrapolation of these data, Hamilton Standard estimated the subject rocket engine could have achieved a total impulse throughput of - 900,000 lbf-sec before exceeding a rule of thumb acceptable roughness of + 25% at Pinlet = 330 psia.

8.1.9.1.3 Findings

State-of-the-art monopropellant hydrazine thrusters have demonstrated the capability to produce greater than 750,000 lb-sec without maintenance extrapolation of these test data indicate up to - 900,000 lb-sec may be possible.

It is recommended that these data be re-mitted to WP-02 for further testing as follows:

- Determine impact of order of magnitude reduction in aniline content on thruster life.
- Conduct tests to determine life of a new thruster designed from the beginning to maximize life.

8.1.9.2 Augmented N₂H₄ Thruster (Waste gas Injection)

8.1.9.2.1 Description

The purpose of this program was to measure the effect of waste gas injection on performance, life and exhaust products of a long life 5-lbf hydrazine thruster. A

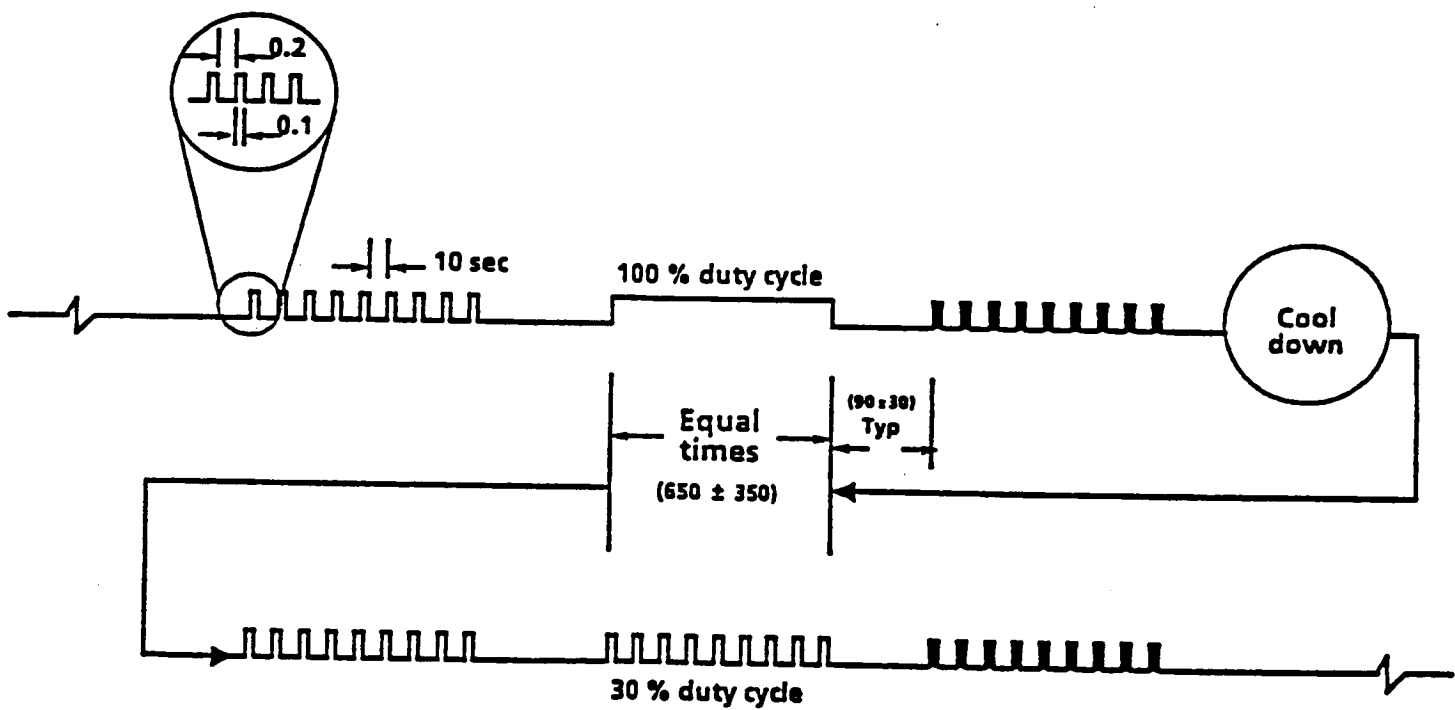


FIGURE 8.1.9.1.1-1 EXTENDED LIFE THRUSTER DUTY CYCLE

spring-loaded catalyst bed was used in the thruster to minimize catalyst loss ratio. Waste gases tested included the expected byproducts of the environmental control and life support system (CO₂ CH₄ N₂) and Argon, presumed to be a byproduct of on-board experiments or material processing. All testing was conducted by Rocket Research Company under subcontract to Boeing Aerospace Company.

8.1.9.2.2. Products

The end product of this program was performance and life margin test data in sufficient detail to permit a demonstration of requirements compliance. The engine data was used to improve the accuracy of analytical predictions.

8.1.9.2.3 Test Results

Performance characteristics necessary of the thruster to meet the reboost requirements are presented below.

Thruster Performance Parameters

Nominal Inlet Pressure	250-400 psia
Minimum Inlet Pressure	33% of Nominal
Maximum Duty Cycle	100%
Minimum Duty Cycle	30%
Maximum On Time	33 minutes
Minimum On Time	0.100 seconds
Total Impulse	160,500 minimum
	750,000 goal
Operating Media	N ₂ H ₄ and decomposition products, CO ₂ , CH ₄ , N ₂ , ARGON

The test set-up is shown in Figure 8.1.9.2.3-1.

A pre-test and post-test checkout of the thruster was performed. The pre-test checkout included tests for engine integrity (pressure test, propellant valve test, etc.). An x-ray of the catalyst bed was taken to determine catalyst bed geometry prior to firing, for comparison with the post test x-ray. Post-test checkout was a repetition of the pretest checkout.

Firing tests consisted of reference performance testing, waste gas Performance Mapping (WGPM) and life testing.

Waste gas was injected on opposing sides of the thruster into a circumferential manifold, just downstream of the catalyst bed. A heat exchanger was used to preheat the waste gases.

Gas samples were taken downstream from the catalyst and waste gas injection locations.

The equation used to quantify the augmentation or Augmentation Ratio (AR) was as follows:

$$AR = \frac{I_{vac} \text{ (combined)}}{\%N_2H_4 \cdot I_{vac} \text{ (WG)} + \%WG \cdot I_{vac} \text{ (WG)}}$$

$$100 \cdot I_{N_2H_4} + 100$$

where Ivac was the combined specific impulse measured, IN₂H₄ was the specific impulse of N₂H₄ measured alone, Ivac (WG) was the Isp of Waste Gas (WG) measured alone, and the percent was the mass fraction.

Figure 8.1.9.2.3-2 shows the results of the experimental measurement and theoretical predictions of AR. A very strong agreement between expected and measured values is shown for argon and nitrogen which

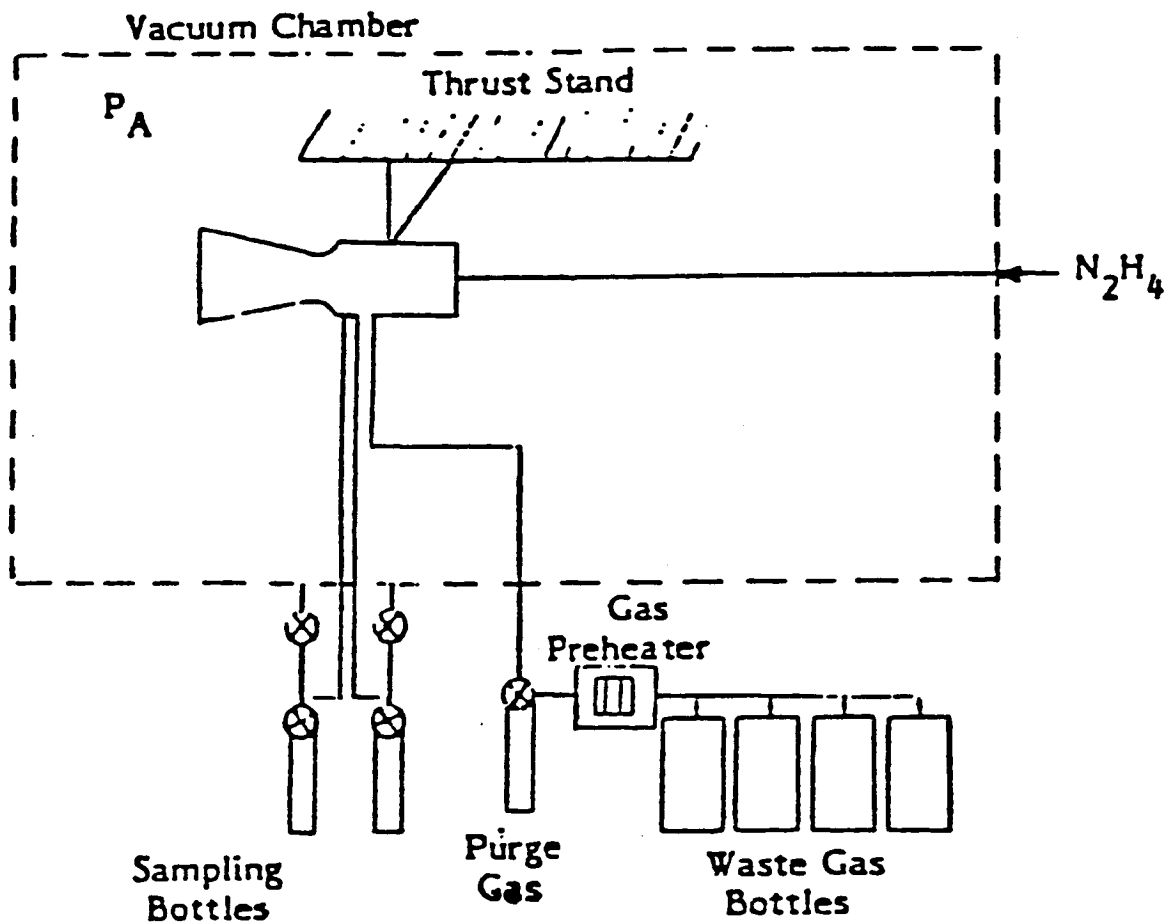


FIGURE 8.1.9.2.3-1 TEST CELL AND THRUSTER SCHEMATIC

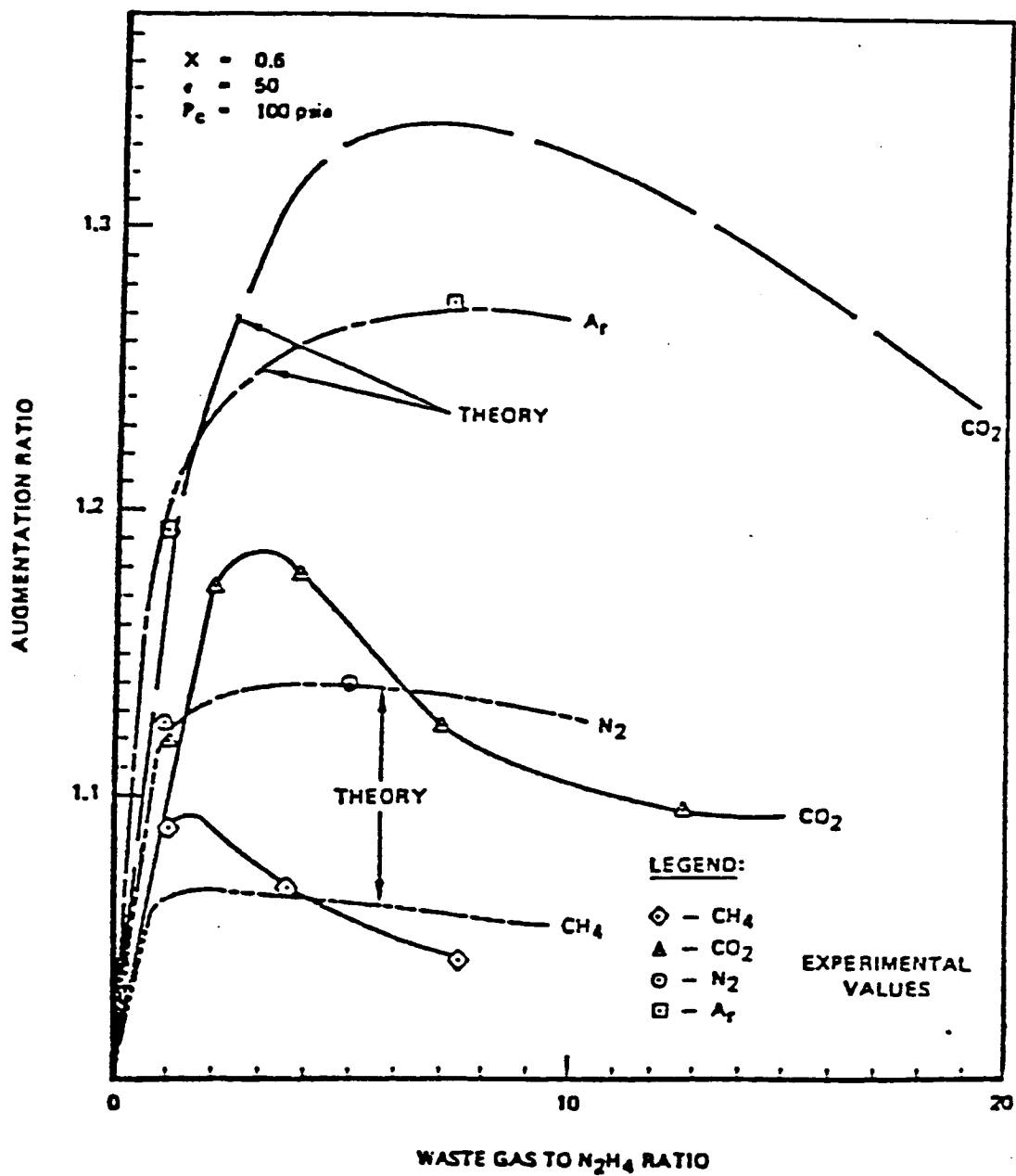


FIGURE 8.1.9.2.3-2 AUGMENTATION RATIO FOR WASTE GAS ADDITION TO HYDRAZINE THRUSTER

are nonreactive. CH₄ and CO₂ in particular have relatively large deviations from the theoretical model.

The test impulse summary presented in Table 8.1.9.2.3-I shows distribution of impulse between tests and individual waste gases. The reference performance test were conducted to assess the engines capabilities as engine hours accumulated. Life tests were performed using 50 percent (by weight) of CO₂, Ar, or N₂ plus 50 percent N₂H₄. Nearly 30 percent of the total impulse was provided by waste gases.

8.1.9.2.4 Findings

An impulse of 807,834 lbf-sec was accumulated, on a long life 5-lbf hydrazine thruster using various waste gases to augment impulse. Post test x-rays indicated approximately 50 percent degradation of the catalyst bed. Based on this testing, Rocket Research estimates the life of this engine to be over 1.5 million lbf-sec.

The amount of Isp augmentation was close to or greater than predicted values, except for CO₂. The discrepancies in the CO₂ data is believed to be caused by the formation of solid carbamates and/or carbonates which reduced the effective Isp.

The waste gas thruster shows promise for the Space Station as a method of disposing of the waste gases accumulated on the Station. The data from these tests should be provided to WP-02 for consideration in the propulsion system design. Further testing of this thruster should be conducted injecting water into the thruster for augmentation. Mixing of CO₂ with other gases to inhibit formation of carbamates and carbonates should be investigated.

8.1.9.3 Minimum Spill Connector

The purpose of this program is to develop a minimum spill disconnect for toxic flu-

ids in space, specifically the design, fabrication and testing of a unit with the capability to purge any remaining fluid which spills/dribbles after the poppet is activated.

8.1.9.3.1 Task Products

The end product will be two connectors which meet the objectives and requirements in Table 8.1.9.3.1-I.

8.1.9.3.2 Test Results Summary

At this date, the connector design shown in Figure 8.1.9.3.2-1 has been completed and long lead parts ordered for fabrication.

8.1.9.4 O₂/H₂ Test Bed Description

The objective of this program is to demonstrate the operation of a complete O₂/H₂ static feed water electrolysis propulsion system. Initial tests will be conducted at an electrolysis pressure of 350 psi. Predicated on the success of these tests subsequent tests are planned at operating pressures of 500 psia, 750 psia and 1000 psia. To accomplish this program, a team with Boeing as test integrator and MSFC as test conductor with support from Rocketdyne, Life Systems Incorporated, and Structural Composites Incorporated, has been formed. Individual responsibilities are presented in Figure 8.1.9.4-1.

8.1.9.4.1 Task Products

These tests will demonstrate technology uncertainties and concerns associated with operation of a high pressure electrolysis-propulsion system. Specifically:

- Can a high pressure static feed electrolysis reliably and safely produce O₂ and H₂ gases?

TABLE 8.1.9.2.3-I IMPULSE SUMMARY

TEST CATEGORY	N ₂ H ₄	IMPULSE SUMMARY (2)				SUBTOTAL	CUMULATIVE TOTAL
		CO ₂	N ₂	CH ₄	ARGON		
Ref. Performance 1	14,253	-	-	-	-	14,253	14,253
Performance Map	8,687 (1)	4,061	2,123	3,340	1,789	21,040	35,293
Ref. Performance 2	15,175	-	-	-	-	15,175 (3)	50,468
life T ests	504,360 (1)	108,690	72,209	-	54,437	739,696	790,164
Ref. Performance 3	17,670	-	-	-	-	17,670 (3)	807,834

560,145 113,291 74,332 3,840 56,226

% N₂H₄ Impulse = 69.3

- (1) Based on N₂H₄ flow rate and Isp correlation from Ref. Performance Tests.
- (2) Wase gas impulse includes effect on augmentation.
- (3) Includes impluse of sequences repeated due to test errors.

TABLE 8.1.9.3.1-I DESIGN PARAMETERS

Fluid Port Size	1/2"
Material Compatibility	- Hydrazine - Isopropyl Alcohol - Deionized Water - Helium - Nitrogen
Pressure Drop (@ 20 GPM)	TBD
Weight	TBD
Max Size Envelope	6 X 6 X 12 Inches
Alignment	
- Lateral Offset	1/8"
- Angular	± 5°
Life Cycle	1000 Cycles
Engagement Force	Max 50 lbs. @ 0 psi
Disengagement Force	Max 50 lbs. @ 0 psi
Proof Pressure	2.0 x Operating Pressure
Burst Pressure	3 x Operating Pressure
Leakage	< $1.4 * 10^{-8}$ sccs He
Working Pressure	Vacuum - 500 psi
Working Temperature	0° F. to 350° F.
Dribble Volume	Zero After Purging

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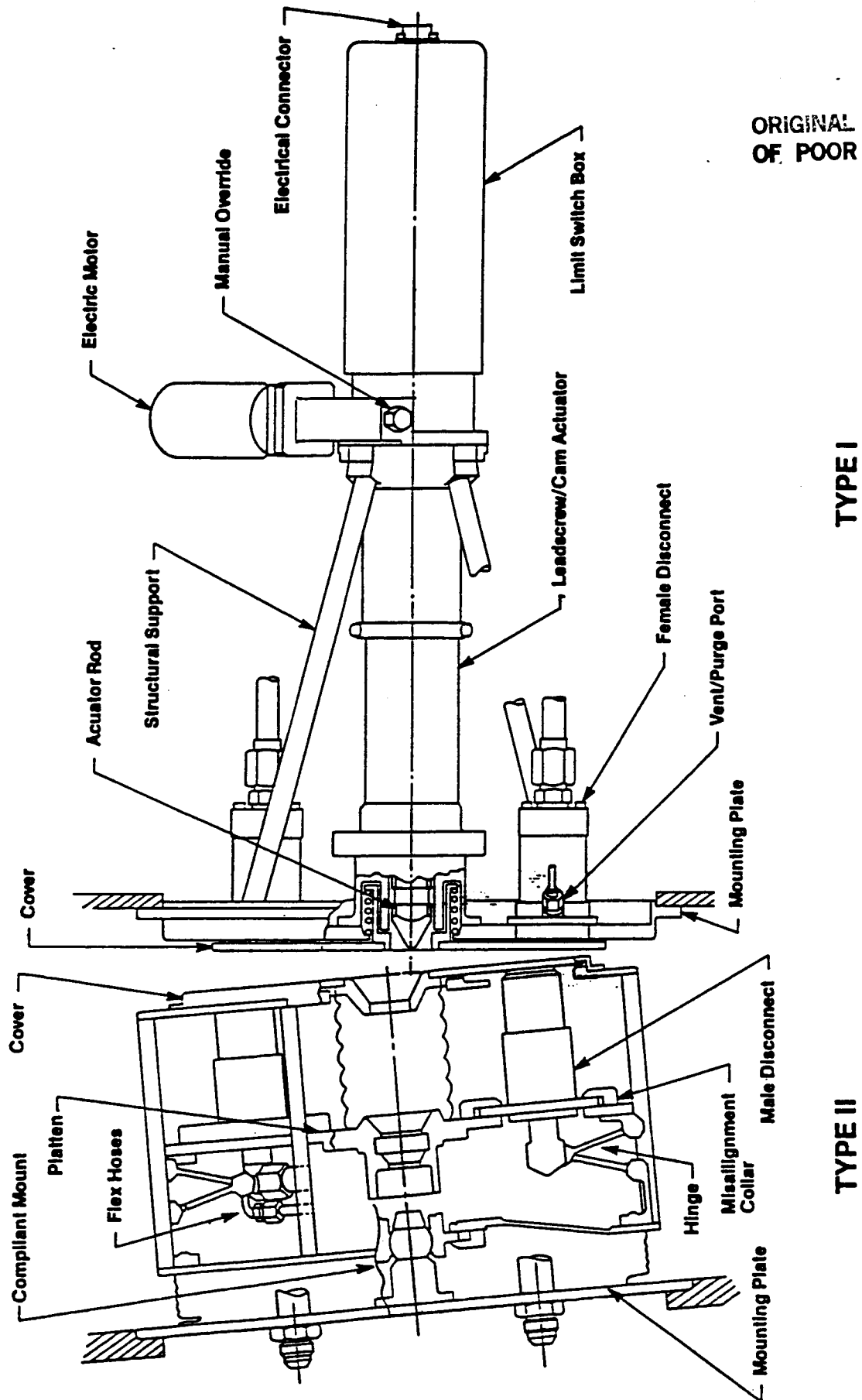


FIGURE 8.1.9.3.2-1 MINIMUM SPILLAGE FLUID CONNECTOR

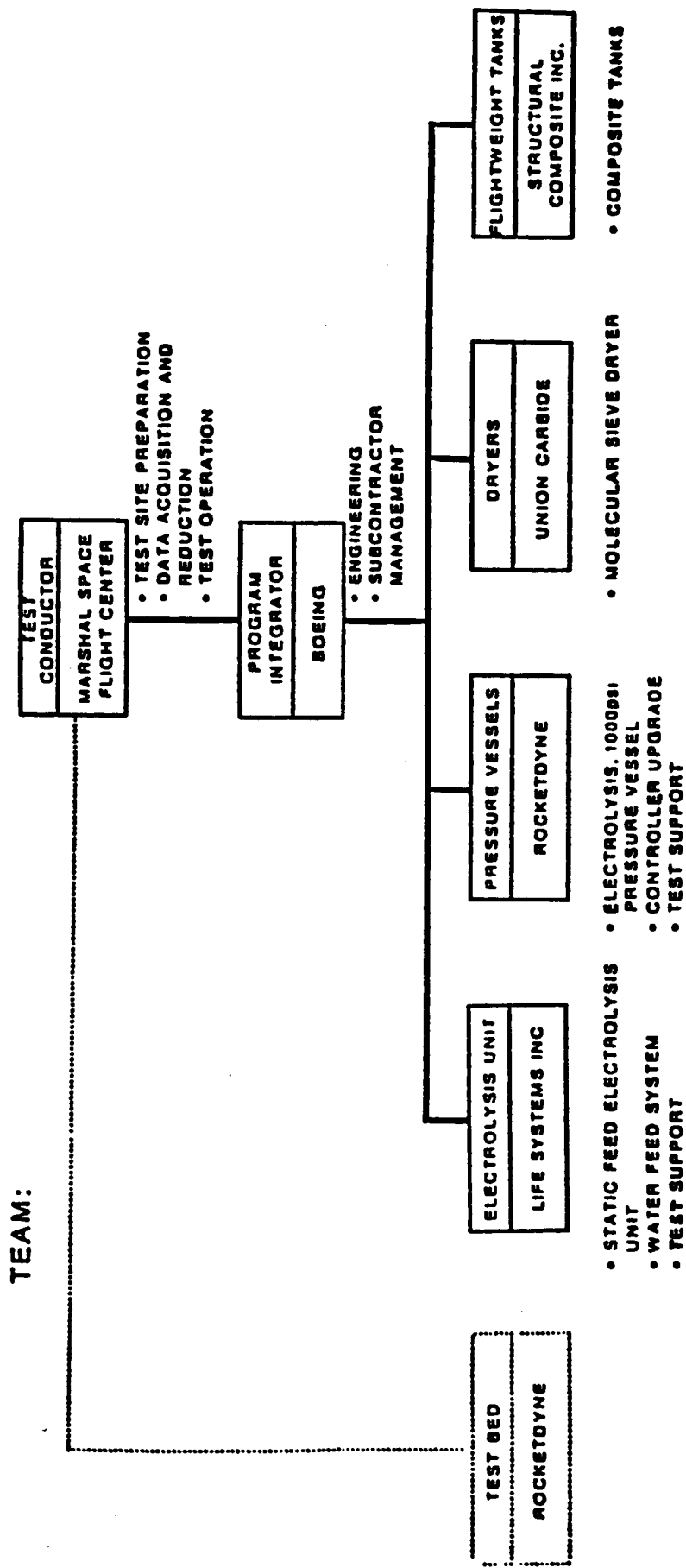


FIGURE 8.1.9.4-1 O₂/H₂ ELECTROLYSIS - PROPULSION TEST TEAM

FIGURE 8.1.9.4-1 O₂/H₂ ELECTROLYSIS - PROPULSION TEST TEAM

Will the O₂ bootstrap pressurization technique work at high pressures?

Can aluminum-lined composite tanks be used to store O₂ and H₂?

Can the mol sieve dryers be regenerated for indefinite life?

Will a full-up system work?

8.1.9.4.2 Analysis and Test Results

The system failure modes and effects analysis has been completed and indicates. There are no outstanding safety issues. Test requirements have been documented for incorporation in the test plan. Preliminary mol sieve tests indicate dryers can be reconstituted by exposure to vacuum with 2500F applied temperature in less than four hours of regeneration time. Single cell 1000 psi electrolysis tests have begun at Life Systems, Inc. Results of these tests will serve as a guide in later full-scale system tests.

8.1.9.4.3 Findings

Preliminary results of analysis and tests conducted have uncovered no major problems date. Final findings and recommendations are pending based on the results of planned testing.

NOTE: Propulsion and Fluids Systems Test is conducted by MSFC

8.1.10 Meteoroid/Debris Impact Shield Testing

Description

The objective of the Meteoroid-Debris Test Program is to determine the effects of space debris and meteoroids on the proposed space station integrated module wall and window designs, and use the test results to determine an optimum design configuration. To accomplish this objec-

tive, 77 representative test specimens of the meteoroid-debris shield and module wall were tested. Five representative window test specimens were also tested. All tests were conducted from July 22, 1985 to March 31, 1986 at the Marshall Space Flight Center light gas gun laboratory.

The penetration control guideline for the inhabited pressurized structure is defined as a 97 percent probability of no penetration in 10 years of service. Critical particle size and density are defined by currently available meteoroid and space debris flux data. Projected increases in man made space debris from future activities is considered. Variables examined during testing of the integrated module wall configuration are: bumper shield thickness and material, standoff distance between the bumper shield and pressure wall, presence of multi-layer insulation, and projectile speed, size, shape and material. All projectile shots in the SM-1 test program struck the test specimen at a normal impact angle.

Findings

- a. Projectile shape does influence penetration results. A tumbling cylinder shaped projectile has a more severe effect on impact than a spherical projectile.
- b. Varying projectile aluminum series of 6061-T6 verses 1100 produced no effect on penetration results.
- c. A six inch standoff between the bumper shield and pressure wall is more desirable than a four inch standoff.
- d. Use of multi-layer insulation, 30 layers of 1/2 millimeter aluminized kap-

ton, significantly improves no penetration capability.

- e. Composite bumper shield material does not provide protection for the pressure wall.
- f. A laminated window pane reduces secondary debris.

Plots of the SM-1 test data are presented in Figures 8.1.10-1, 8.1.10-2 and 8.1.10-3.

- g. During the SM-1 test program, normal angle impacts were considered to be the most severe impact angle for design. However, subsequent testing has shown oblique angle impacts to be more critical than normal impacts⁴. Furthermore, oblique angle collisions are more likely to occur than normal angle collisions⁵.
- h. For normal angle impacts, a 0.063 inch bumper was more effective than a 0.040 inch thick bumper shield. However, for oblique angle impacts, the opposite proved to be true due to the thicker bumper creating larger shrapnel from the bumper shield itself.

8.1.10.1 Recommendations

Consider using a variable meteoroid-debris shield. A single 0.040 inch shield is sufficient for the walls between the modules and interconnects, the half of each module protected by other areas of the module configuration. These walls are subject to meteoroid strikes only and not space debris. The exposed half of each module will utilize a double bumper configuration, two 0.020 inch thick sheets one inch apart stabilized by a central core.

Consider installing the bumper shield on orbit. The advantages are: increased launch capability for module interior items, a greater standoff between the bumper and pressure wall can be achieved, and the shield latch-release mechanisms can be simplified since they would not have to endure launch loads.

8.1.11 DM-1 System Controller

Development for Data Management Systems

8.1.11.1 Description

DM-1 is concerned with the fault-tolerance and data acquisition aspects of high speed, distributed, multiple-redundant Data Management Systems (DMS).

Fault tolerance schemes were being studied because of high availability, reliability and safety requirements for manned spacecraft control system computers. Fault tolerance is probably the only available technique for satisfying these requirements. Tasks in defining a fault-tolerance concept include: 1) using Space Station Program reliability requirements and DMS architecture concepts to define a fault tolerant philosophy for architecture components, and 2) designing an implementation for the fault tolerant philosophy, maximizing system reliability in performance of fault detection, fault isolation, damage containment and recovery.

Another significant component of this effort is the data acquisition and control of subsystem elements. It is estimated that there will be hundreds of sensors and effectors in each module. These data points will have to be serviced at or near their source with the use of a multiplexer/demultiplexer device (MDM), and this information passed on to the appropriate subsystem controller. Since this same process will need to be repeated for each

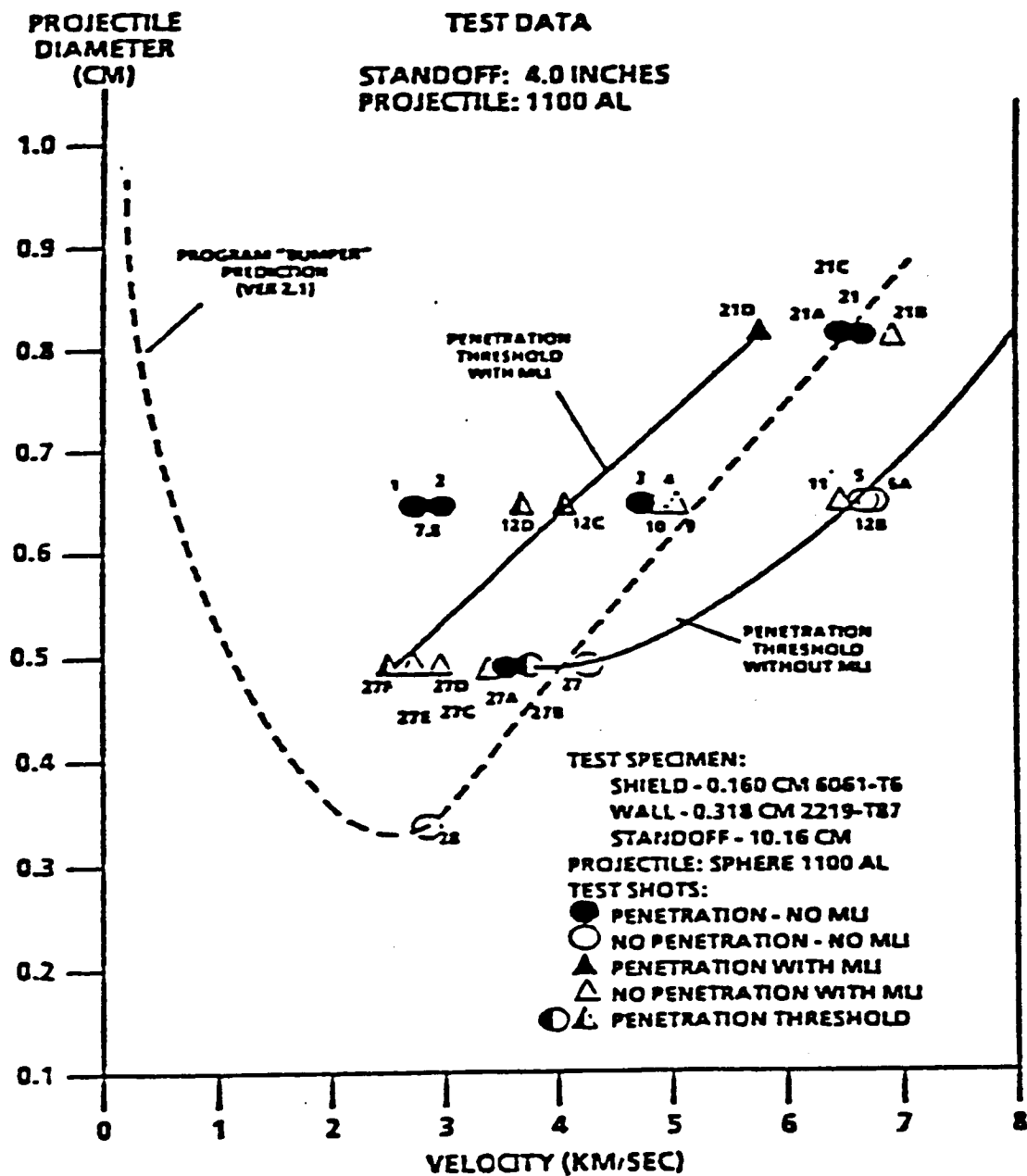


FIGURE 8.1.10-1 ADP SM-1 METEORIOD DEBRIS IMPACT SHIELD TESTING

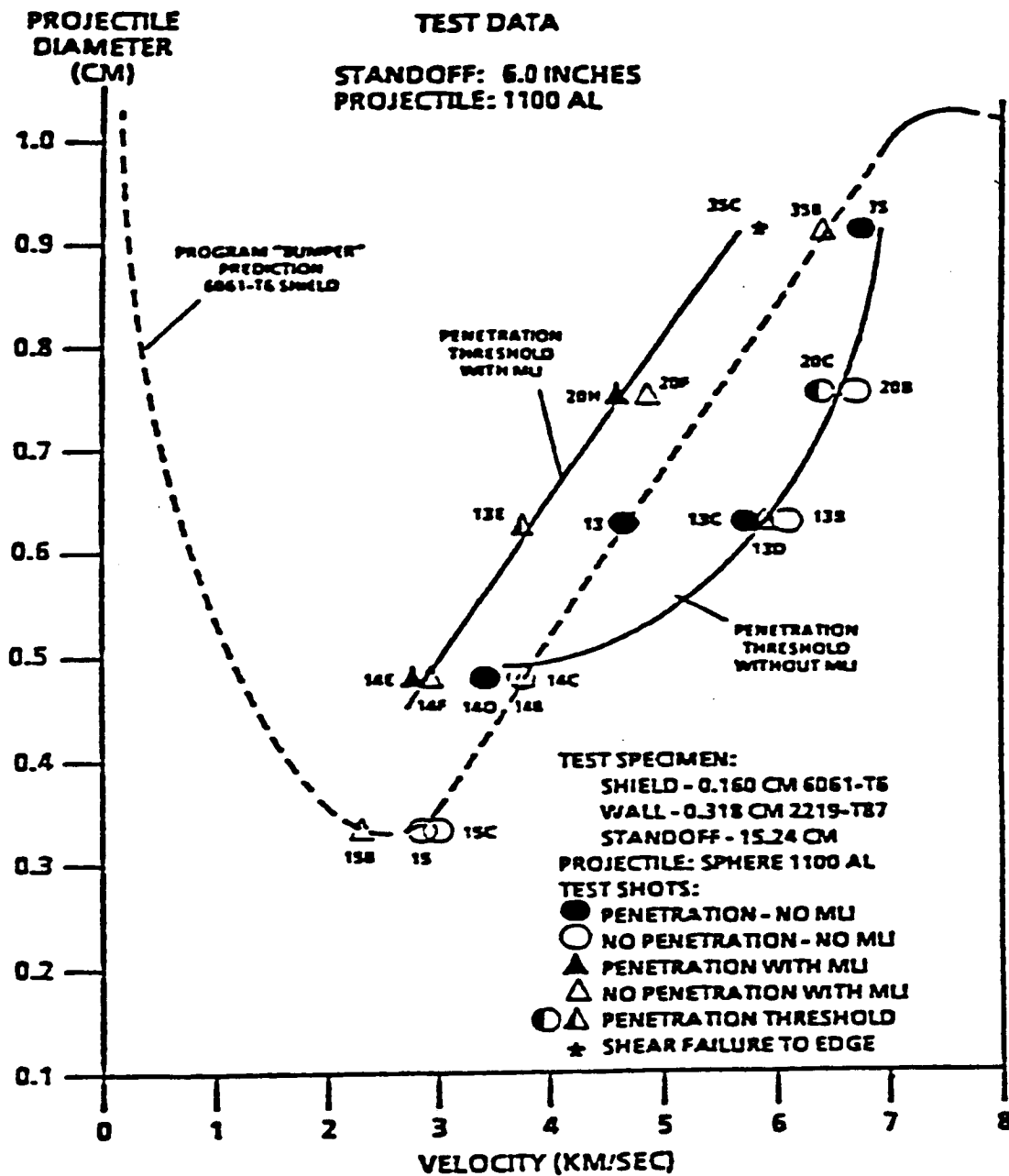


FIGURE 8.1.10-2 ADP SM-1 METEORIOD DEBRIS IMPACT SHIELD TESTING

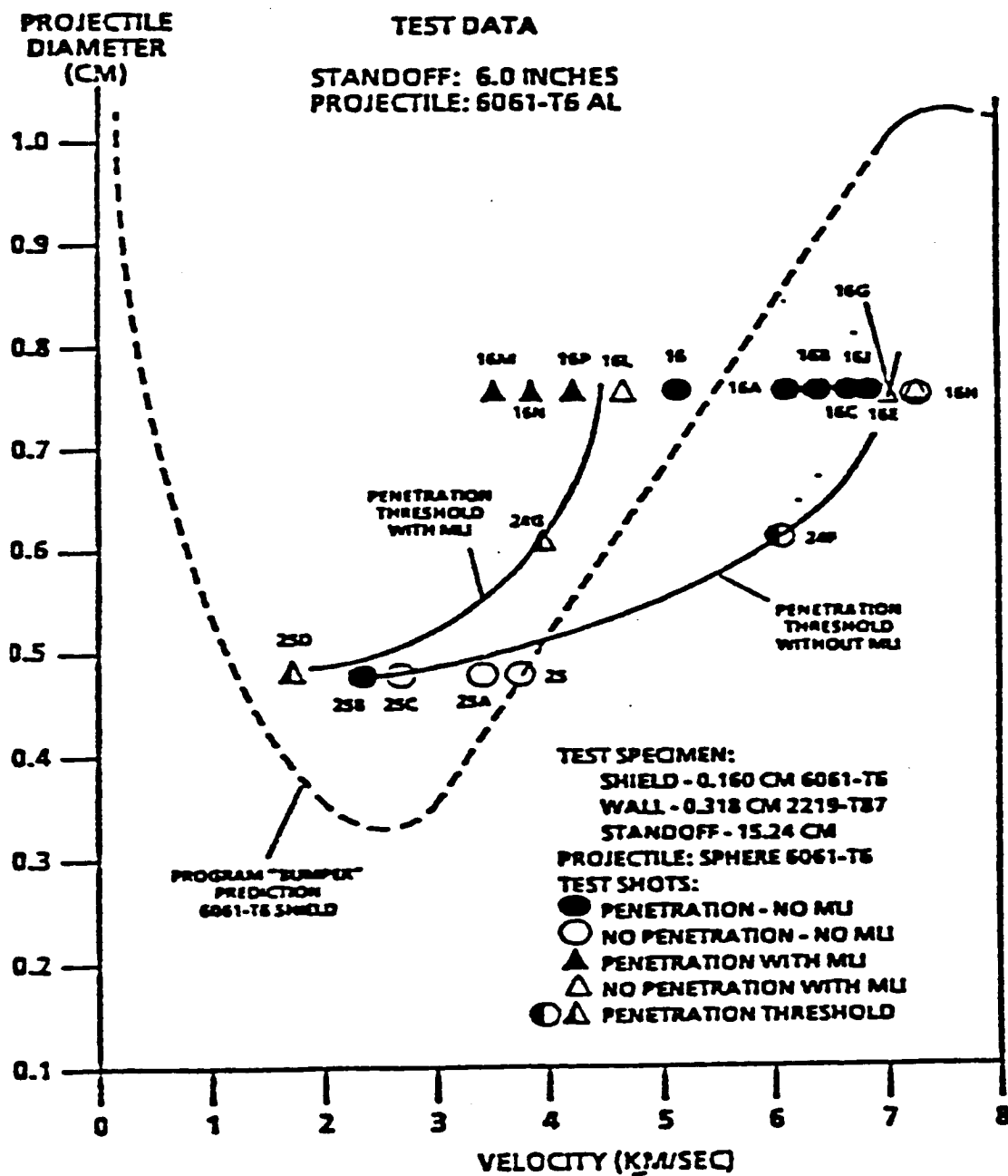


FIGURE 8.1.10-3 ADP SM-1 METEORIOD DEBRIS IMPACT SHIELD TESTING

rack, a substantial savings in the total lines of software could be realized if a portion of this code could be duplicated for all subsystems. Early definition of this repeated code will allow earlier development of application software. Therefore, the concept of Generic Data Acquisition and Control (GDAC) software was developed. Tasks include: 1) develop requirements for data acquisition and control subsystem analysis and application software requirements, 2) develop and implement GDAC software written in Ada on a MIL-STD-1750A machine in control of sensors and effectors, 3) define graphic Ada modules that will implement the requirements and be usable by application software, and 4) use the prototype software and the knowledge gained in 2) to implement the generic data acquisition and control.

8.1.11.2 Products

The products that result from this effort are:

- Fault tolerant architecture and recovery schemes for a two tiered architecture that can be used to design inherently fault-tolerant SDPs and MDMs.
- GDAC software that will include scan routines for data acquisition, engineering unit conversion schemes, PID control methods, sensor data acquisition methods, control algorithms and status reporting techniques. Use of Ada generics will ease software validation costs.

8.1.11.3 Test Results Summary

Analysis of fault tolerance in DMS architectures showed that special processor ar-

chitectures are required to achieve high reliability in SDPs and MDMs. Recommendations were made for these architectures and fault detection, fault isolation, damage containment, recovery and repair procedures were outlined. Additionally, it was found that the use of pooled spares in SDPs adds greatly to the flexibility, modularity and reliability of functions performed by those components, but requires significant design integration with DMS hardware and software (particularly the OS, NOS, bootstrap ROM and module or station management functions). Another finding was that the sharing of MDMs between subsystems provided a much lower component count (and thus higher reliability and lower weight)—benefits which offset the cost of integration between subsystems.

Analysis of data acquisition and control requirements for subsystems showed common requirements for data monitoring. A design approach was selected which partitioned a small set of functions to the MDM or SDP. Requirements were derived for these functions. Using the requirements, data flow diagrams and a software architecture were developed. The output will be a common set of software for each application-defined low-level functions. GDAC concepts are being implemented in a testbed that uses a MicroVAX as a standard data processor, a Mikros MIL-STD-1750A computer (equipped with analog and digital I/O capability) as an MDM and the System Designers cross-compiler. The testbed also includes a Tektronix development system and the necessary software for Ada development. Prototype GDAC software has been developed. Tests will be performed using a sensor/effector test box to checkout data acquisition and control algorithms and rudimentary closed loop control strategies.

8.1.12 DM-2 Hierarchical Controller Development

8.1.12.1 Description

The goal of this project is to develop consistent module, subsystem and component control concepts which can be applied to WP-01 subsystems. We will build on IR&D research in which we adapted our Supervisory Control and Data Acquisition System to control the thermal and electrical power subsystem testbed hardware. We will test the performance of this software in thermal subsystem control. Additionally, we will add ECLSS and Experiment Control components and displays to our SCADA system.

From our experience with these subsystems, requirements for data acquisition and distribution services which are to be fully or partially implemented in Data Management System (DMS) software will be developed.

The final stage of this effort will be to develop reusable Ada components and to incorporate these into our hierarchical control software architecture.

As a separate subtask, we will study the testability aspects of artificial intelligence software. Although A.I. techniques offer promise to Space Station automation applications, they have not been developed with traditional software life cycle considerations as a goal. Safety workshops at recent A.I. conferences have called in to question the advisability of using current techniques in critical applications. Under subcontract, Vanderbilt University Center for Intelligent System will survey the current state-of-the-art, identify problem areas, prepare potential solutions and make recommendations in this area.

Note: For additional details on the Boeing ADP projects refer to DR-19 item DP

1.6(c) Advance Development Test Results and Assessments, dated October 24, 1986.

8.2 Advanced Development Growth Recommendations

The recommendations for growth Space Station advanced development is provided herein in response to the paragraph 3.4.3 (c-15) of the S.O.W. The following areas are recommended for development:

- Data Development and Communication
- Electrocal/Electronic
- Thermal
- Propulsion/Fluid Management
- ECLSS
- Software
- Automation/Robotics

Criteria for selection of growth technology candidates are:

- Increase productivity
- Improved crew and station safety
- Increased autonomy
- Improved technology transfer
- Lower cost

The following recommendations are provided.

8.2.1 Data Management and Communications

Task Title: Processors for Artificial Intelligence

Discipline/Subsystem: Data Management

Task Description: The purpose of this task is to investigate computer designs qualified for the processing of Artificial In-

telligence application in space environments. The resulting hardware may be founded on any of the several currently discussed architectures, these being (1) LISP processors, (2) data flow machines, (3) demand driven, or (4) conventional (Von Neuman) machines. This task might also be expected to identify necessary support software, especially for parallel execution environments.

Task Title: Advanced Video Systems

Discipline/Subsystem: Data Management and Communications

Task Description: Video image processing for the 1988-1995 time frame exists in the area of High Speed Video Image Analysis. This will allow experimenters the use of video analysis to record the pertinent information in a high speed motion experiment, such as combustion diagnostics, and provide the data to be downlinked immediately instead of waiting for the motion picture film return. Video Image analysis can be used to relieve the station specialist that humans would miss in a periodic inspection.

Task Title: Integrated Voice Recognition System

Discipline/Subsystem: Data Management and Communication

Task Description: The purpose of this advanced development task is to 1) investigate the latest voice recognition systems and determine the feasibility of their use in the Space Station distributed audio system, and 2) perform a detailed analysis to determine the utilization of a voice recognition system on the station. The benefit which could be realized from having highly reliable voice recognition system available for use at any distributed audio location is considerable. The effect on crew and mission efficiency with the utilization of voice recognition should be stud-

ied. The possibility of using voice recognition for berthing and docking, for the teleoperation and for EVA tasks could greatly effect the overall Space Station efficiency.

8.2.2 Electrical/Electronic

Task Title: Solid State Remote Power Controllers

Discipline/Subsystem: Electrical Power

Task Description: Changes in solid state device technology will result in greater utilization of solid state remote power controllers at higher current levels. Current technology limits utilization to units in the 10-20 Amps range based upon weight, volume, and thermal considerations. With the development of higher efficiency solid state componentry and paralleling techniques, smaller and cooler operating devices are conceivable in the 1988-1995 time frame.

From a size and weight standpoint, advanced development in the area of power control should be followed to reduce installed equipment volume and weight as technology matures.

Task Title: Advanced Sensors

Discipline/Subsystem: Electrical Power

Task Description: Current technology voltage and current sensors are relatively large and heavy in comparison to associated componentry. With continued Space Station growth, additional sensor requirements will be created, increasing overall installed equipment weight and diminishing available volume. Advanced developed in the area of sensors should be guided towards miniturized non-contracting devices replacing conventional scalar voltage and current sensors for the purpose of sensing vector power flow and having a standardized digital signal format output.

In addition to voltage and current devices, requirements for temperature and phase sensors may become necessary to provide optimum utilization of available power levels due to increased availability and distribution of power and more reactive loads.

8.2.3 Thermal

Task Title: Two Phase Thermal Transport System

Discipline/Subsystem: Thermal

Task Description: Develop two-phase water thermal transport technology for application inside laboratory modules for cooling high-heat-load, isothermal customer requirements.

8.2.4 Propulsion/Fluid Management

Task Title: Composite Cryogenic Tanks

Discipline/Subsystem: Propulsion/Fluid Management

Task Description: Develop and demonstrate light weight composite cryogenic tanks capable of long term space storage of cryogenic fluids. Composite structure tanks offer the benefit of one-half the weight savings of existing metal cryogenic fluids tanks.

Task Title: Fluids Refrigeration and Liquification

Discipline/Subsystem: Propulsion/Fluids Management

Task Description: Develop and demonstrate a system capability of refrigeration and reliquification of fluids such as N₂, O₂, H₂ on board the Space Station.

Task Title: Electrolysis Propulsion System

Discipline/Subsystem: Propulsion

Task Description: Develop and demonstrate an electrolysis O₂/H₂ propulsion system capable of using waste water as its propellant. Utilization of this waste product eliminates the need to provide logistics to orbit for a propellant and eliminates the logistics to ground for a waste product. The electrolysis approach offers high volumetric efficiency by minimizing propellant storage volume.

8.2.5 ECLSS

Task Title: High Efficiency Oxygen Recovery

Discipline/Subsystem: ECLSS

Task Description: Develop a simplified high efficiency process for direct conversion of carbon dioxide into carbon and oxygen in lieu of the the conventional complex process of CO₂ reduction to water and oxygen generation by electrolysis. Video Tracking would greatly improve the capability for proximity operations such as OMV, and EVA. Crewmen could be released from the tedious tasks of camera pointing and concentrate on MRMS operation, and other more demanding tasks.

Digital video transmission on fiber optic cable would reduce weight, power consumption, and size, and improve performance capabilities. Advances in video processing techniques and circuits could greatly reduce power consumption as well as weight. Constraints on the format for the video signal from experimenters could be eased and allow much more useful data collection from the experiments.

Task Title: Integrated Waste and Water Management

Discipline/Subsystem: ECLSS

Task Description: Develop a process that collects urine, feces, humidity condensate and non-metallic trash and process this waste material into potable water, into useable gases (such as N₂ and CO₂) and the remainder into a high density residue for logistics return from orbit.

Task Title: Toxic Waste Management

Discipline/Subsystem: ECLSS

Task Description: Develop and demonstrate a toxic waste management technology that handles a wide range of lab effluents and wastes with minimum crew involvement.

8.2.6 Software

Task Title: Validation and Test for A.I. Software

Discipline/Subsystem: Software

Task Description: The purpose of this task is to analyze, classify, and document procedures by which Artificial Intelligence software may be validated and tested. Of specific interest to AI are procedures related to discovery errors in:

- I/O, i.e., data acquisition and conclusion presentation.
- Inferencing scheme, i.e., modeling "reasoning."
- Control strategy appropriateness.
- Test case formulation and mix to reflect
 - Diverse conditions
 - Probes of system competence "boundaries"
 - Problem class overlap ambiguities.

- Conclusions for "hard" problems identified by experts.

Task Title: Integration of all into Conventionally Based Software Systems.

Discipline/Subsystem: Software

Task Description: Add operating system constructs to network operating system and host operating system that will support integration of symbolic processing (AI) elements with the real time procedural processing environment. Since the majority of IOC software will probably be Ada, this integration must make use of the Ada run-time support equipment for tasking, signaling, and monitor blackboard services. The goal of this task would be (a) minimum impact on existing operating systems, (b) low overhead in context switches and parameter passing, and (c) guaranteed maintenance of real time capability.

8.2.7 Automation/Robotics

Task Title: Experiment Support Teleoperator

Discipline/Subsystem: Automation/Robotics

Task Description: Development of a teleoperated mechanism capable of mimicking human manipulative functions. The system would allow ground operators seated at a work station to manipulate experimental tasks by moving arms and fingers in reaction to images on one or more CRTs. System would operate on a stand-alone basis (24 hours per day minus maintenance and experiment change out).

Task Title: Automation and Robotics

Discipline/Subsystem: Logistics Module Automation

Task Description: Development of a robotic inventory management system to retrieve/replace ORUs from storage. Establish conceptual design of a carriage mechanism that could be centrally located in the logistics module. Examine SOA of manipulators and sensors to locate/remove/replace components. Develop software and man/machine operations. Design, fabricate and test a brassboard system, follow with prototype demonstration.

Task Title: Integrated Safety Monitor

Discipline/Subsystem: Integrated Safety Monitor

Task Description: Development of an AI assisted system to detect, isolate and appropriately respond to safety and other fault related concerns. This task will investigate the feasibility of using AI technology to detect safety hazards in a general setting, assess their likely cause, and to generate advice and/or control actions. Develop a demonstration that would focus initially on atmospheric contamination, loss of atmosphere and fire.

Task Title: Integrated Crew Information System

Discipline/Subsystem: Automation/Robotics

Task Description: Development of an AI aided system to intelligently prioritize and display information competing for crew attention. Initial task would investigate and

implement logic that imitates the human prioritization process. The IOC approach will no doubt be query/response and human-directed data base and information needs. The growth crew information system evolves toward a more symbolic man/machine interface, configuration, architecture, and topology.

Task Title: Active Inventory Sensing System

Discipline/Subsystem: Automation/Robotics

Task Description: Development of an active tracking system for critical inventory items including consumables to facilitate logistics operations and minimize crew involvement.

This is an investigation of the feasibility of actively tracking inventory for large numbers of critical items. "Active" here implies automatic tracking without human involvement. The intention is to investigate ways and means by which such tracking could be accomplished, and would include radio, infrared and ultrasonic principles. Consideration would be given to packing concepts to support active detection of reorder points, as well as to detect the presence or absence of critical tools, etc.

9.0 TECHNICAL AND MANAGEMENT INFORMATION SYSTEM (TMIS)

9.1 Description

The Technical and Management Information System (TMIS), shown in Figure 9.1-1, that will support Phase C/D Work Package 1 has been demonstrated as an integrated and distributed computing environment satisfying the following requirements:

- a. Analysis
- b. CAD/CAE
- c. Documentation
- d. Presentation
- e. Electronic Mail
- f. Schedules
- g. Statusing

The TMIS computing environment, activated as part of Phase B, contains the hardware and software resources required to analyze, design, and manage the work package configuration in Phase C/D. It satisfies program control requirements for automated office functions and provides program management visibility of schedules and status. TMIS has the electronic interfaces to business, financial, materiel, and operations systems. The electronic transfer of the engineering bill of materials, developed and released as part of the design process, gives the non-engineering systems the necessary data for effective cost management and overall product assurance and configuration control.

The TMIS computing environment centers around two core computers, the general purpose Engineering VAX 11/780 and the Intergraph CAD/CAE VAX 11/785. These two computers, connected using DECNET,

host the majority of the analytical, design, configuration control, and management software packages. Auxiliary tools are provided by IBM and Zenith personal computers. The personal computers support the Space Station design by supplying engineering personnel with the desktop resources required to analyze, document and present the visibility necessary for management approval.

The TMIS computing environment design has the facility for information exchange at all levels. VAX electronic mail is used to coordinate and exchange data at the engineering and support group levels. Available on both the general purpose and Intergraph VAX computers, the mail facilities are used for; 1) day to day message exchange, and 2) the assembly of text and graphic documentation files for final editing of released documents. Mail messages are also exchanged internally and externally using IBM PROFS by Space Station management. PROFS accounts were used to establish the link between MSFC and BAC TMIS. This connectivity was tested and demonstrated during Phase B and is used to transmit ASCII text, non-cad graphics and CAD datasets.

The following paragraphs detail the capabilities of the TMIS computing environment used in the engineering design process. Other sections describe the program management systems which will be used in Phase C/D.

9.2 TMIS Engineering Systems

BAC has in operation a division dated TMIS system to electronically accommodate engineering data generated during all phases of the SSP. These data include all deliverable documentation (i.e., docu-

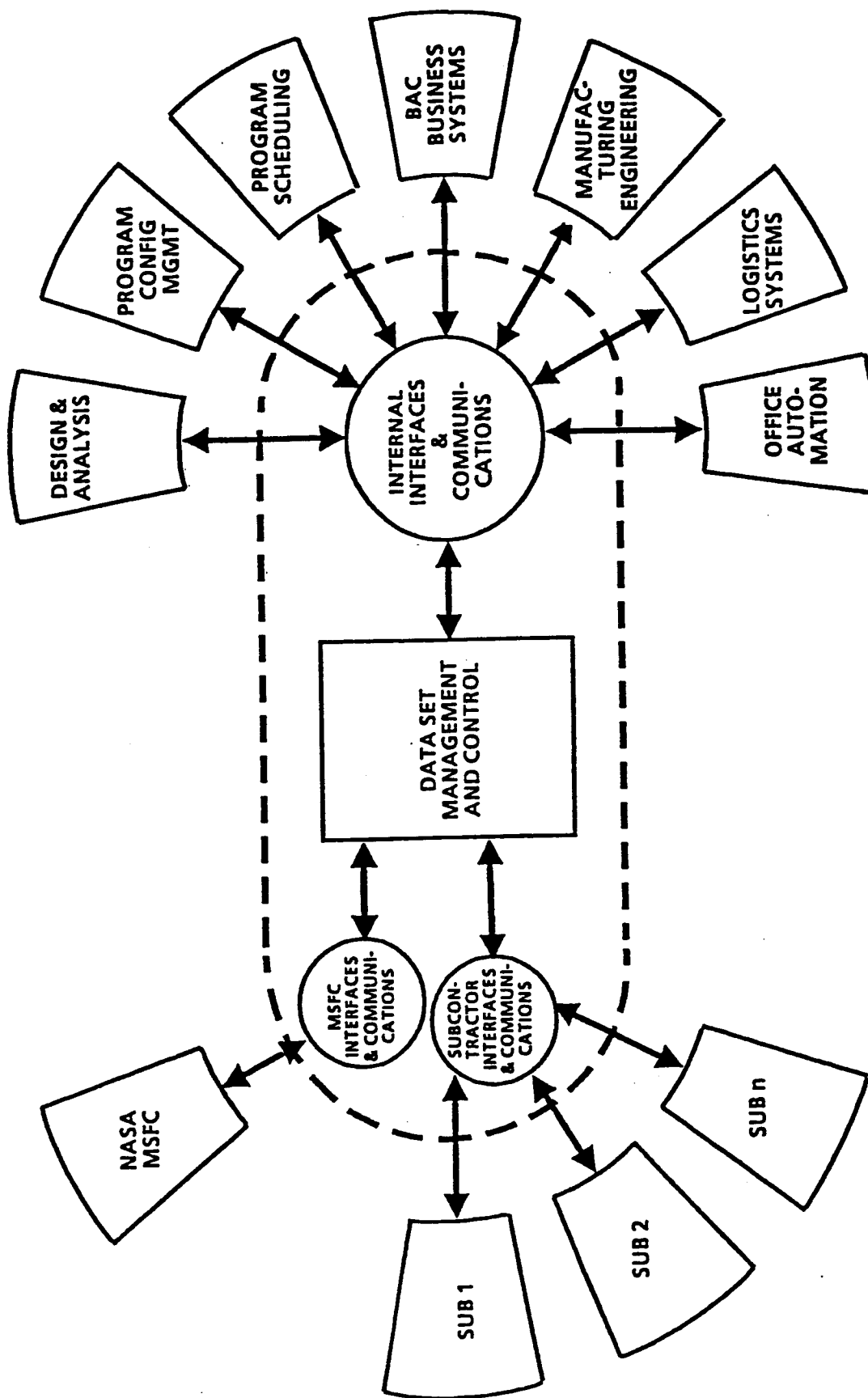


FIGURE 9.1-1 TECHNICAL AND MANAGEMENT INFORMATION SYSTEM

ments and drawings), models, incoming and outgoing correspondence, subcontractor and other agencies' data, and internal memoranda and reports.

The objective of TMIS is to minimize paper generation by providing the necessary computing systems hardware, software tools, and the interfacing between these systems to support the SSP engineering effort. This electronic support includes data collection and storage, engineering release and control, sign off, and delivery.

The TMIS system has been designed with a modular structure to provide for growth, technological improvements, and procedure revisions. TMIS also has been designed for a large number of users, and its users have access to tailored training plan designed to enhance productivity.

9.2.1 Analytical Systems and Supporting Tools

Various tools were implemented to streamline the engineering and engineering management process. These tools support engineering design and analysis, design reviews, and configuration management. In supporting systems engineering and integration, they also accumulate statistics that provide visibility for management decisions leading to productivity improvements.

9.2.2 Computer Aided Design System

A key objective of the TMIS is the electronic delivery to NASA of drawings and design models in a format compatible with NASA CAD/CAE systems. A second objective is to support a high level of CAD/CAE productivity. Both of these objectives are being achieved by 1) utilizing an Intergraph CAD/CAE system, already in place;

2) incorporation of design standards and Boeing procedures into customized menus; and 3) by the use of standard exchange formats.

All CAD models and drawings (mechanical, electrical, and electronic) electronically delivered as released data are fully compatible with the NASA MSFC SSP Intergraph system. Compatibility has been achieved by delivering these data in the Interactive Graphics Design Software (IGDS) format. The one exception is 3D models developed using GEOMOD. These models are delivered in GEOMOD Universal format.

The CAD/CAE host computer executes the design and analysis software to supporting a cluster of workstations. In addition to providing computational support for the workstations, the host also acts as a local file server. The basic system provides interactive 3-D geometric construction, analysis, modification, and drafting functions. The system also provides for finite element modeling, solid modeling, schematic and printed circuit board design and analysis.

9.2.2.1 Mechanical and Structural Design

The Intergraph mechanical and structural CAD system provides for the design of the Space Station end item component parts. In addition to the CAD data, an engineering database will be maintained which contains non-graphic data such as that necessary for the bill of materials (BOM) and for design analysis. The data base includes items such as part quantity, indented parts list, used-on parts list, mass, material and process specifications, and revisions. This non-graphical data will be

9.2.2.2 Electrical and Electronic Design (Phase C/D)

The Intergraph electrical and electronic CAD system provides for the design of schematics, printed circuit boards, wiring diagrams, and cables and harnesses datasets. In addition to the CAD data, an engineering data base will be maintained which will contain non-graphic data such as wire lists, equipment lists, and bill of materials. This data will be retrievable for query and report generation independent of the graphic environment.

9.2.2.3 Modeling and Analysis Support

TMIS provides CAE computational support for various modeling, simulation, and analysis studies to support SSP systems engineering and integration. These studies include solid and wireframe models, finite element modeling, circuit timing, reliability analysis, failure modes analysis, stress analysis, dynamics and loads, thermal analysis, propulsion analysis, mass properties, and electrical and electronic analysis. Most of these studies are performed on VAX or PC based equipment. The data from these studies are maintained in an engineering database and will be retrievable in support of the CAD effort.

9.2.3 Engineering Computer Data Storage

The engineering computer data is stored as shown in Figure 9.2.3-1. The data may originate from the Intergraph CAD/CAE system, the General Purpose (GP) VAX, local PC data bases, word processing, the laboratory, Mentor system (electrical design), or other systems used by subcontractors. All work in progress data shared among the various engineering organizations are stored on the GP VAX 11/780 except for CAD/CAE data which are stored on the Intergraph VAX. In addition,

all released engineering data or that which are to be released, are stored in the electronic vault on the GP VAX, using DEC Engineering Data Control System (EDCS) Softwares.

9.2.3.1 Sole Authority Dataset

All engineering data such as documents, drawings, and data bases will be controlled and released as shown in Figure 9.2.3-1 by using the VAX based system EDCS (Engineering Data Control System). The procedures to implement this system follow the Boeing release standards. However, the electronic dataset, not the hardcopy, will be the sole authority. Document, drawing, and database approval and signoff will be performed electronically.

9.2.3.2 Electronic Data Vault

The electronic data vault contains the reference configuration, pre-release, release, and historical data bases. EDCS provides an audit trail in support of configuration management of these data bases and various other types of data. In addition, EDCS provides a library index capability for query, dataset copy capability, and report generation. Also, this system has the capability to maintain proprietary rights of the users.

The electronic data vault eventually will contain several tens of gigabytes of data. The quantity of data will prevent daily full backups. Therefore, the data vault will be incrementally backed up on a daily basis. Full backups will be performed weekly.

9.2.3.3 Electronic Data Transfer

TMIS has the demonstrated capability to transfer data between the various internal computer systems, subcontractors, and MSFC via interconnections as shown in Figure 9.2.3.3-1.

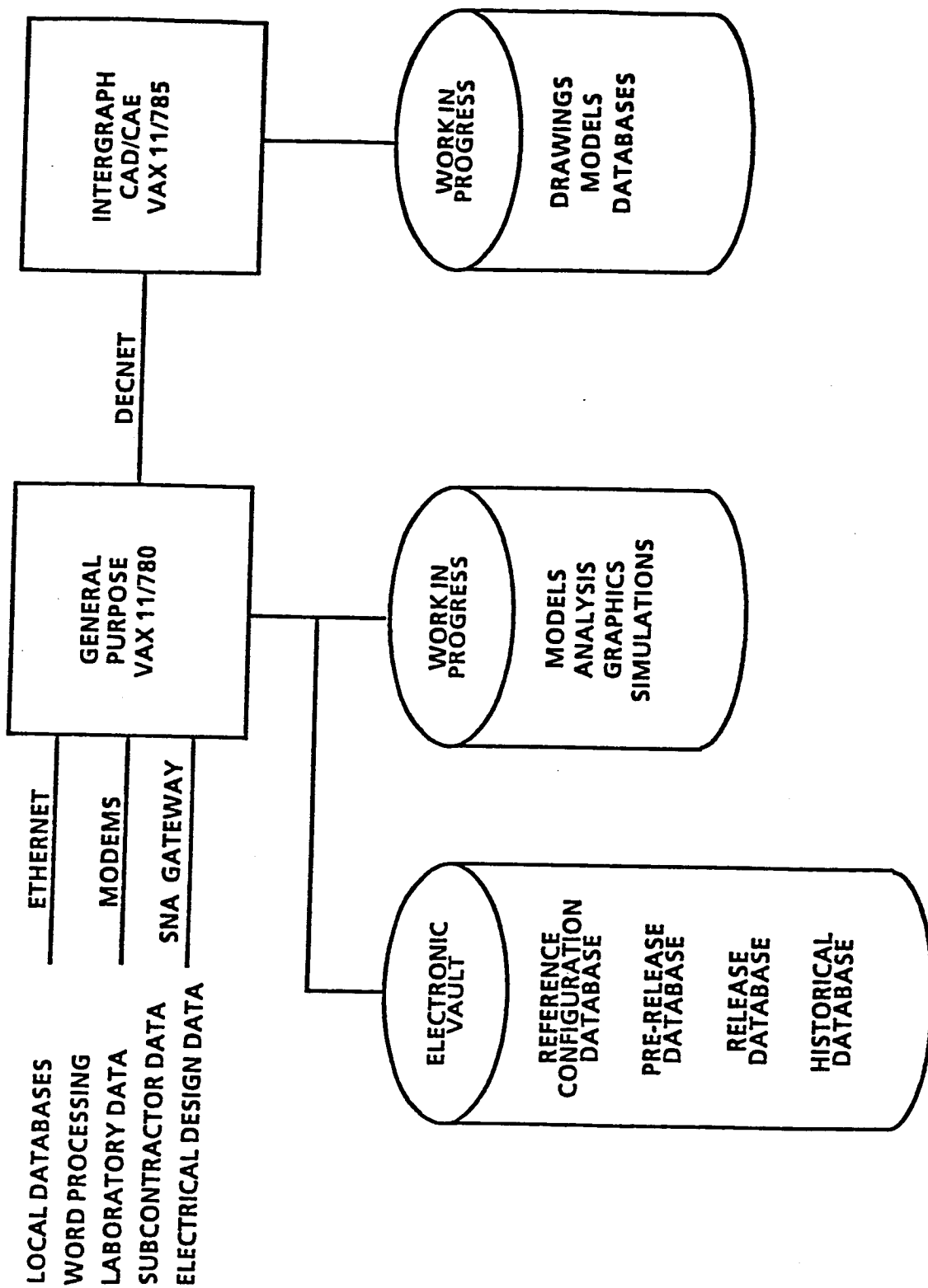


FIGURE 9.2.3-1 ENGINEERING DATASET STORAGE

FIGURE 9.2.3-1 ENGINEERING DATASET STORAGE

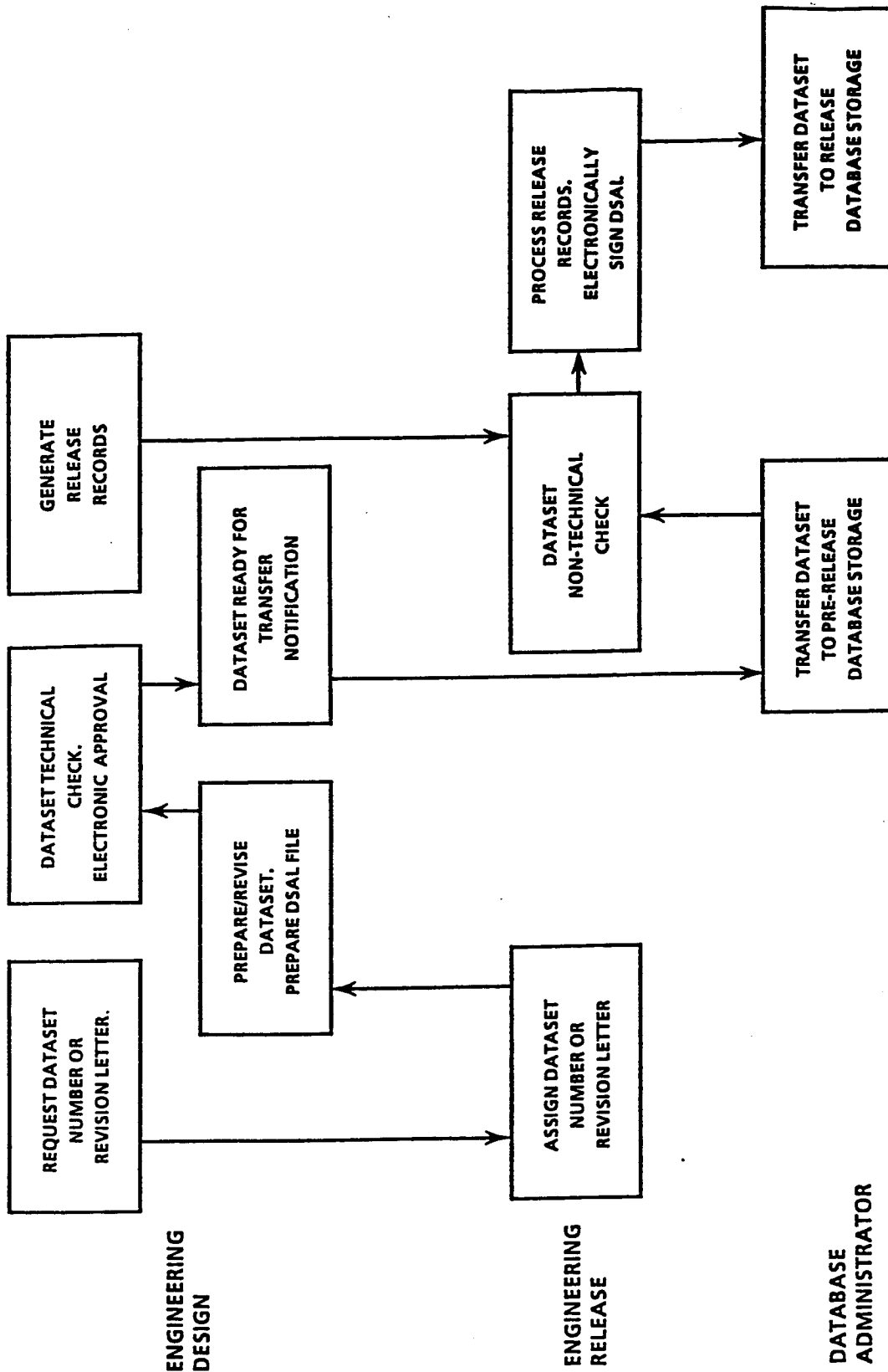


FIGURE 9.2.3.1-1 ENGINEERING RELEASE AND CONTROL OF DATASETS

FIGURE 9.2.3.1-1 ENGINEERING RELEASE AND CONTROL OF DATASETS

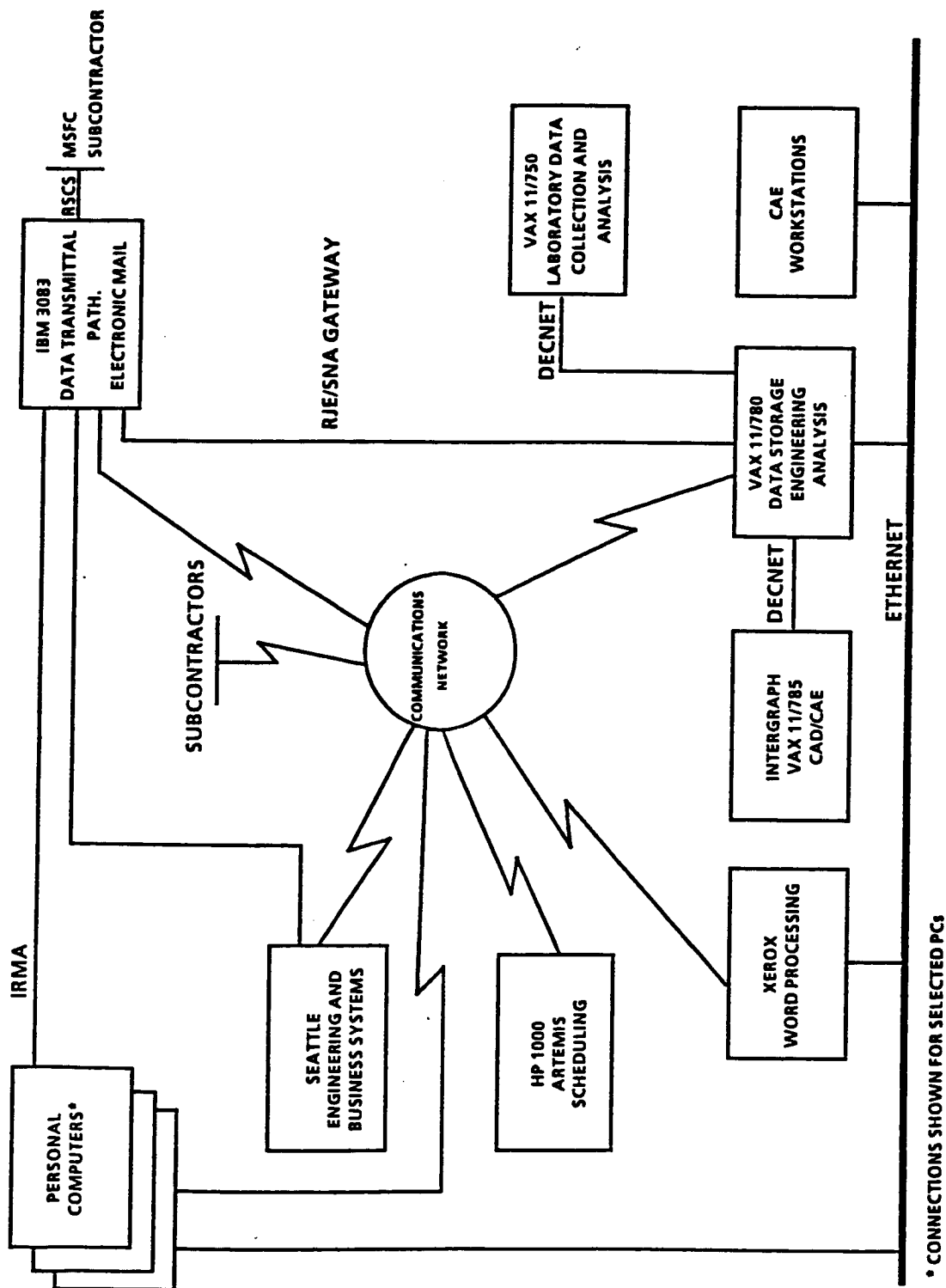


FIGURE 9.2.3.3-1 TMS DATA TRANSFER INTERCONNECTIONS

FIGURE 9.2.2.4-1 TMS DATA TRANSFER INTERCONNECTIONS

All BAC managers, supervisors, and the data library have PROFS accounts for transfer of electronic mail with each other and MSFC.

9.2.3.3.1 Intersystem Connectivity for Data Transfer

To support the capabilities described above, TMIS will include a number of computer systems distributed throughout various Boeing buildings. These systems will be linked together as shown in Figure 9-4. Some of these linkages provide data access backup in case of hardware failure. The goal is that one failure does not incapacitate TMIS nor does it cause additional failures. Maintenance is being performed without interference with other TMIS operations.

9.2.3.3.2 External Data Transfer and System Linkage

All electronic data deliveries to NASA are being transmitted to MSFC's IBM 4381 from BAC's IBM 3083 via RSCS. The data are sent to a special account specifically for BAC data. For each dataset delivered, a Dataset Control Sheet (DCS) is transmit-

ted to a special PROFS account as a record of data delivery.

Currently, the IBM 3083 has an interface to a GFE 9.6 kilobaud line. The interface will be upgraded as necessary if the GFE line is upgraded.

All CAD data will be delivered electronically as specified in Section 2.4.2.2.2. All non-CAD graphics, i.e., figures and viewgraphs, is optionally delivered electronically in DI-3000 Metafile format. All documentation text electronically delivered is generated in clear ASCII. The only non-printable characters generated will be carriage returns, line feeds, form feeds, and blanks. The clear ASCII is then being translated to EBCDIC before transmitting to MSFC. All document text and figures, if printed, will conform to the format specified by MSFC such as JSC 30200, Documentation Format Requirements or equivalent. The BAC data base containing data pertinent to the Space Station reference configuration are maintained and delivered in RIM 7 unload format. All other data bases are maintained and delivered in R:base 5000 format.

BOEING

ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
1						45					
2						46					
3						47					
4						48					
5						49					
6						50					
7						51					
8						52					
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ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
89						131					
90						132					
91						133					
92						134					
93						135					
94						136					
95						137					
96						138					
97						139					
98						140					
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THE **BOEING** COMPANY

ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
162						223					
163						224					
164						225					
165						226					
166						227					
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ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
263						304					
264						305					
265						306					
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ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
344						384					
345						385					
346						386					
347						387					
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349						389					
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ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
424						464					
425						465					
426						466					
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428						468					
429						469					
430						470					
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